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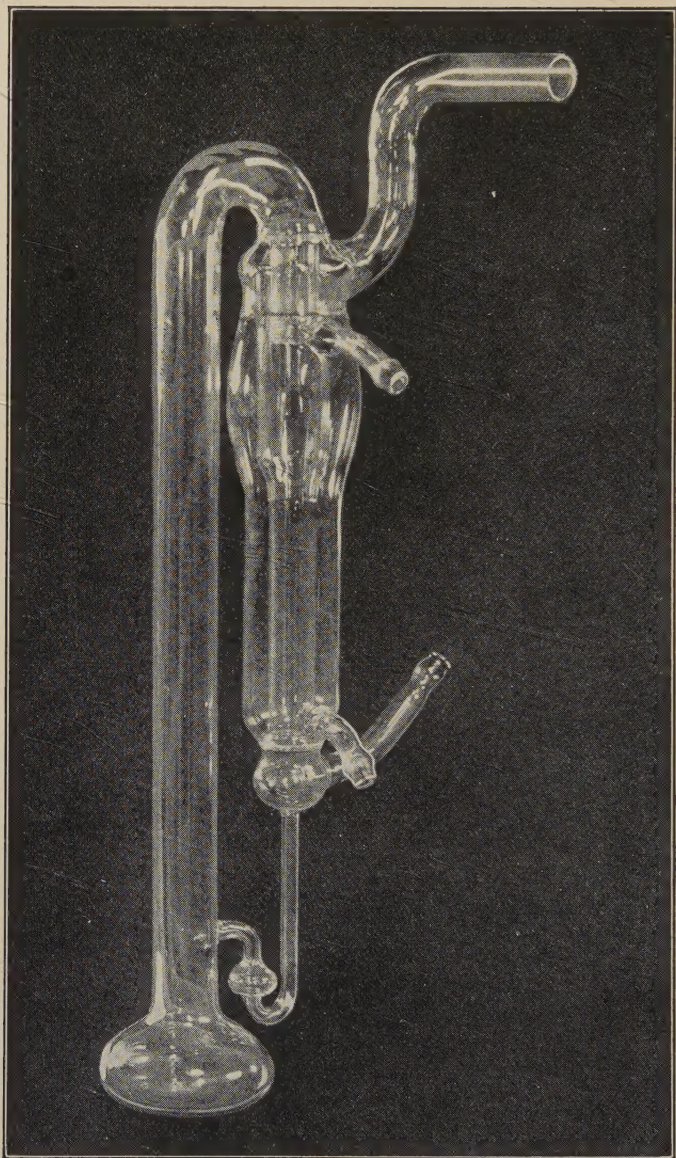


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Dr. Robert Watkins

LABORATORY GLASS BLOWING



(Frontispiece)

Mercury vapor vacuum pump constructed from Pyrex Laboratory Glass; practically all the fundamental operations in glass blowing are illustrated in this apparatus.

LABORATORY GLASS BLOWING

PUBLISHED FORMERLY UNDER THE TITLE OF
LABORATORY MANUAL OF GLASS BLOWING

BY

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PREFACE

In the fourteen years that have passed since the first publication of my "Laboratory Manual of Glass Blowing," there have been some important changes in the problems confronting the laboratory glass worker, particularly on account of the introduction of Pyrex glass. The steady demand for the book, requiring two reprintings during these years, has made it seem worth while to amplify it and bring it up to date. As I have had little personal touch with the art of glass blowing in recent years, I have entrusted the revision and enlargement of the book to my friends and co-workers, Messrs. Junius D. Edwards and Cyril S. Taylor. Out of their practical experience they have made a few alterations and have added a considerable amount of new material which we believe will be of value to those who have occasion to work glass in the physical and chemical laboratory.

The purpose of this book is to provide a clear and detailed discussion of the elements of glass working. Many laboratories in this country, especially in the West, are located a long way from any professional glass blower, and the time and money spent in shipping broken apparatus several hundred miles to be mended could often be saved if some of the laboratory force could seal on a new stop cock, replace a broken tube, or make some temporary repairs. Many men in physical or chemical laboratories have occasion to modify some piece of apparatus, designed, perhaps, for other uses, or to design new apparatus. To such the ability to perform some of the operations herein described may also be very valuable.

No originality is claimed for the methods here described. They are those which the authors have found most suitable and convenient in their own work and most easily learned by students. The aim has been to describe each operation in such detail that a beginner can follow the process without help and, with practice, attain satisfactory results. It is, however, much easier to perform any of the operations described after seeing someone else perform it correctly, since the temperature, the exact time to begin blowing the glass, and many other details are very difficult to obtain from a description.

It has not been thought worth while to describe the process of making stop cocks, thermometers, vacuum tubes, and so forth, as such things can be purchased more cheaply and of much better quality than any amateur can make unless he is willing to spend a very large amount of time in practice. For similar reasons, the manipulation of quartz glass has been omitted, but the practical importance of Pyrex glass in the laboratory and its increasing popularity seemed to justify a description of methods for working it.

The authors will be grateful for all suggestions and criticisms tending to improve the methods presented. If some of them appear to be given in excessive detail, the reader will remember that many things which are obvious to the experienced worker are not so to the beginner and that it is the little details in the manipulation which often spell success or failure in glass blowing.

Acknowledgment is due Mr. F. Kraissl, of the Corning Glass Company, for many suggestions regarding the working of Pyrex glass and to Mr. George W. Morey, of the Geophysical Laboratory, Carnegie Institution, Washington, D. C., for the information on the composition of the various glasses as given in Table 1.

OAKMONT, PA.
March, 1928.

FRANCIS C. FRARY.

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LABORATORY GLASS BLOWING

CHAPTER I

GLASS AND ITS WORKING CHARACTERISTICS

Some knowledge of glass is fundamental to a study of glass working. A tender consideration must be shown for its mechanical and thermal properties, if glass is to be successfully fashioned into the many forms in which it is used in the laboratory. Glass is an amorphous material which is hard and rigid at room temperatures, but when it is heated it gradually softens and becomes less viscous. The change on heating is continuous from the temperature at which it is a rigid solid to temperatures at which it becomes a thin liquid; glass has no melting point or melting range. Heating glass, even to a low temperature, produces some softening, even though it may not be ordinarily appreciable. At temperatures of several hundred degrees Centigrade, however, the degree of softening is quite important. The temperature at which glass softens enough to work varies appreciably with the composition of the glass.

One of the most important factors in the success of any piece of glass blowing is the glass employed. There are many varieties of glass available for glass-blowing operations. The two most generally useful

TABLE 1.—ANALYSES OF A NUMBER OF TYPES OF GLASS TUBING
(Table Prepared by George W. Morey, Geophysical Laboratory, Carnegie Institution, Washington)

	1	2	3	4	5	6	7	8	9	10	11	12
SiO ₂	80.75	72.86	64.7	79.57	66.90	66.58	69.30	69.10	71.88	61.26	68.69	61.5
B ₂ O ₃	12.00	10.43	10.9	.....	7.22	0.91	.....	.....	.....	.....	.....	.....
Na ₂ O.....	4.10	9.82	7.5	0.66	1.25	14.80	12.80	14.50	18.57	13.08	15.87	8.8
K ₂ O.....	0.10	0.10	0.37	11.60	2.40	tr	4.96	6.38	1.98	3.98	7.32	5.3
CaO.....	0.30	0.35	0.63	7.80	7.94	7.18	8.28	6.89	4.90	9.25	5.66	.....
ZnO.....	.....	.....	10.9	.....	7.27	6.24	.....	.....	.....	.....	.....	.....
MgO.....	.....	0.20	0.21	0.11	0.61	0.17	0.07	0.20	0.20	0.20	0.24	.....
Al ₂ O ₃	2.20 {	6.24	4.2	0.32	6.38	3.84	4.05	3.10	2.75	7.92	2.11 {	0.8
Fe ₂ O ₃		tr	0.25	0.04	0.22	tr	0.18	.....	.....	0.30		
Mn ₂ O ₃.....	.....	tr	0.01	.....	.....	0.28	0.20	0.10	0.10	0.30	.....	.....
Sb ₂ O ₃.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.45	.....	.....
PbO.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.6
As ₂ O ₅	0.40	.....	0.14	.....	.....	.....	tr	0.10	0.10	.....	.....	.....

1. Pyrex laboratory glass.

2. Schott, borosilicate thermometer 59^{IV}.

3. Schott, Jena *geräte*.

4. Kavalier combustion tube.

5. Jena combustion tube.

6. Schott, normal thermometer 16^{III}.

7. A good German lamp-working tubing.

8. Similar to 7.

9. A good French lamp-working tubing.

10. Good German tubing with tendency to discolor.

11. Inferior Thuringian glass.

12. Lead glass.

kinds for laboratory work are lime-soda glass and the low-expansion borosilicate glass known as Pyrex laboratory glass. A lead glass is used but to a lesser extent. Other glasses are available for special purposes. The composition of a variety of types of glass tubing is shown in Table 1.

Soft Glass.

Glass-blowing tubing of the kind rather vaguely known as *soft glass* is usually a lime-soda glass, although potash constitutes part of the alkali content. A small percentage of potash seems to decrease the devitrifying tendency of the glass. Some of the *hard* glasses carry more potash than soda in their makeup. The soft glass from different makers will vary in composition, and, if not carefully controlled, glass from different batches of the same maker may vary considerably in composition and properties. Uniformity of properties is necessary where more or less complicated pieces of apparatus are to be put together from different pieces of glass.

When working with unknown lots of glass which are to be joined together, it is advisable to make a small test joint first. If the glass fuses together nicely and if the joint does not crack upon cooling and upon tapping it rather vigorously upon a wooden block, it may be assumed that the two lots of glass are near enough alike to be joined together.

The following qualities are desirable in a soft glass for ordinary working:

1. Moderately low working temperature.
2. Freedom from air bubbles, striations, and irregularities.

3. Proper composition so that the glass will not devitrify or crystallize while being handled at its working temperature.

4. Ability to withstand fairly rapid heating without cracking.

The working temperature of different samples of so-called *soft glass* varies a good deal and is best determined by trial. The glass should become almost soft enough for blowing in a flame which still shows a little yellow near the tip, so that at the highest temperature of the flame it may flow fairly freely and, thus, easily eliminate irregularities in thickness. If the glass is too hard, the shrinking of the glass, collection of material for a bulb, and, in fact, most of the working processes will be slower, and the glass will not stay at its working temperature long enough after its removal from the flame to permit it to be blown readily.

Air bubbles in the original batch of glass are drawn out into long, hairlike tubes during the process of manufacture. When such tubing is worked, the walls of these microscopic tubes may collapse in spots, and the air thus enclosed will often collect as a small bubble in the wall, thus weakening it. Occasionally, one end of one of these microscopic tubes will connect with the interior of the tube, and the other end will be open on the outside of the tube. Such a piece of glass, if used in an apparatus to hold high vacuum, will be a constant source of leakage. This condition can usually be detected by determining whether a colored liquid, such as dyed alcohol, will be drawn up by capillarity into the suspected opening.

Irregularities are of various kinds. Some of the larger sizes of thin-walled tubing often have one half of their walls much thicker than the other, and such tubing should be used only for the simplest work. Some tubing has occasional knots or lumps of unfused material. The rest of the tube is usually all right, but often the defective part must be cut out. The presence of striations running along the tube is, generally, an indication of hard, inferior glass. Crookedness and non-uniformity of diameter are troublesome only when long pieces must be used.

Devitrification.

Devitrification is one of the worst faults glass can possibly have. It is especially common in old glass and in glass which has contained acids. It seems to be of two sorts. One variety manifests itself on the surface of the glass before it reaches its working temperature, but if the glass be heated to the highest temperature of the flame it will disappear except in the portion at the edge of the heated part. The glass seems to work all right, but an ugly, crystallized ring is left at the edge of the portion heated. This kind appears most frequently in old glass which was originally of good quality but has, in time, been superficially altered, probably by the loss of alkalies. The other variety of devitrification does not appear when the glass is first heated; but after it has been maintained at or above its working temperature for a longer or shorter time, it will be noticed that the outer surface has lost its smoothness and appears to be covered with minute wrinkles. It will, also, be found that the glass has become harder, so that it

becomes impossible to work it easily. Further heating only makes the matter worse, as does the use of a higher temperature from the start. In fact, it will often be found that a piece of comparatively soft glass which devitrifies almost at once in a "hissing" flame can be worked without serious difficulty if care be taken to use a flame still decidedly tinged with yellow. Even good glass will begin to devitrify in this way if heated too long at the highest temperature of the flame, so care should always be taken (1) to reduce the time of heating of any spot of glass to a minimum, *i.e.*, get the desired result at the first attempt, if possible, or at least with the minimum of reheating and "doctoring," and (2) to avoid keeping the glass at the highest temperature of the flame any longer than necessary. This may be accomplished by doing all heating, shrinking, etc., of the glass in a flame more or less tinged with yellow and raising the temperature to the highest point only when ready to blow the glass. This kind of devitrification is apparently due to volatilization of the alkalis from the glass in the flame.

Devitrification is fundamentally the result of surface alteration of the glass. Old glass apparently undergoes a kind of weathering as a result of the action of moisture and carbon dioxide upon the oxides of the glass. Under certain conditions, it has been noted that old glass will show an efflorescence of sodium bicarbonate upon the surface, and such a glass shows a marked tendency to devitrify upon heating. Germann¹ believes that heating drives off water, leaving dehydrated or separated silica on the surface, which

¹ GERMANN, A. F. O.: *J. Am. Chem. Soc.*, **43**, 11 (1921).

is responsible for the devitrified appearance after heating. In some cases, this excess silica will redissolve in the underlying silicates upon heating and the glass partially clears up as previously noted. Germann found, however, that if the glass were washed first with dilute hydrofluoric acid to remove the silica, it would then work in the flame just as if it were new glass. Glass which has lost alkali by volatilization as the result of too long heating in the flame may also be washed with hydrofluoric acid and reheated without devitrification. This treatment should be very useful in the repair of old glass apparatus.

It is said that devitrification caused by volatilization of the alkalies from glass can be partly remedied or prevented by heating the glass in a strong "sodium" flame. This is accomplished by wrapping asbestos paper around a piece of tubing, saturating it with a strong salt solution, and holding it in the flame as the glass is heated.

In order to avoid, as far as possible, this weathering or aging, glass should be stored in a *dry* place free from acid vapor and laboratory fumes. In handling, care should also be taken to avoid scratching of tubing by drawing one piece over another. Scratched tubing is especially susceptible to breakage. In fact, it is common practice to scratch a tube preparatory to breaking it in two.

Annealing.

The toughness of glass, *i.e.*, its ability to withstand variations of temperature, depends on its composition and the care taken in its annealing. In general, large pieces of glass should be heated very slowly in

the smoky flame, and the larger the diameter of the tube the greater the length which must be kept warm to prevent cracking. All large pieces should be carefully heated over their whole circumference to the point where the soot deposit burns off, before being finally cooled. After being thus heated, they are cooled in a large, smoky flame until well coated with soot; then the flame is gradually reduced in size, and the object finally cooled in the hot air above it until it will not set fire to cotton. If thought necessary, it may then be well wrapped in cotton and allowed to cool in the air. If not properly annealed, the place heated may crack spontaneously when cold, and it is quite certain to crack if it is reheated later.

Pyrex¹ Laboratory Glass.

Not all of the above remarks are applicable in the case of Pyrex glass. Pyrex glass softens at a considerably higher temperature than soft glass, so that the flame tinged with yellow will not furnish a temperature hot enough to soften the glass properly. In fact, a special burner or special means must usually be employed to produce the necessary temperature. As Pyrex glass will become rigid more quickly than lime-soda or lead glass when removed from the flame, the removal and blowing should be carried out more rapidly than is necessary with soft glass. Pyrex glass is a high-silica glass and has a very low temperature coefficient of expansion. It can, therefore,

¹ Pyrex is a trade mark owned and used by the Corning Glass Works, Corning, N. Y., for a group of its special low-expansion glasses. The glass referred to as Pyrex, throughout this book, is Pyrex laboratory glass.

be introduced into the flame and heated up at a much greater rate than is permissible in the case of soft glass. Also, the precaution of allowing the article to cool slowly in a smoky flame is not usually necessary. If Pyrex glass is reheated too often or at a too-high temperature, it tends to become opaque. This is not detrimental to its usefulness but may spoil its appearance.

Lead Glass.

Lead glass carries a substantial percentage of lead oxide and is softer and more readily fusible than lime-soda glass. It is used in the manufacture of lamp bulbs, vacuum tubes, etc., and by professional glass blowers. It has the disagreeable property of turning black in a few seconds unless worked in a strongly oxidizing flame. This may be prevented by using a "hissing" flame, with a large excess of air, and working in the extreme end of the flame; or the black lead may thus be reoxidized and the glass restored to its original clearness.

Glass-blowing Flame.

Next in importance to the glass is the flame in which the glass is to be worked. Any good blast lamp, such as is ordinarily used in a chemical laboratory for the ignition of precipitates, will be satisfactory for soft glass, provided it gives a smooth, regular flame of sufficient size for the work in hand, and when turned down will give a sharp-pointed flame of well-defined parts. Manufactured gas as supplied for domestic use makes an ideal fuel for such a lamp, but, where it is not available, some laboratories use

"gasoline gas" made by saturating air with gasoline vapor in special apparatus. Most laboratories are now supplied with low-pressure air, which can be used for operating the lamp. There is also available on the market a number of small-capacity compressors large enough to operate a blast lamp and which can be conveniently used for this purpose where compressed air is not continually "on tap." A Bunsen burner should also be close at hand on the work table, as it is a valuable adjunct to the blast lamp in many operations.

The laboratory type of bellows with rubber diaphragm can be used if it gives a steady supply of air under sufficient pressure for the maximum size of flame to be used. A bellows with a leaky valve will give a pulsating flame which is very annoying and makes good work very difficult. Where much glass blowing is being done, the operation of the foot bellows is tedious, to say the least.

It is very difficult to operate the ordinary glass-blowing lamp with natural gas and compressed air and secure a flame which can be varied in size as needed and not be continually blowing out. A lamp can be operated satisfactorily, however, with natural gas and air enriched with oxygen. The flame is very hot, naturally, and only the simplest operation can be performed in it with soft glass. Pyrex glass, however, can be handled very satisfactorily with it. Special lamps are now available for use with natural gas and compressed air.

Pyrex glass tubing requires a higher temperature than soft glass for easy working, and, therefore, it is very essential to have a blowpipe or blast lamp so

equipped that it will produce the higher temperature required. While the smaller sizes of tubing up to about 1/2 inch in diameter will soften sufficiently in the ordinary gas-air blast lamp and still better in the so-called *cross fires*, which will soften Pyrex glass tubing up to 1 inch in diameter, the addition of oxygen is necessary when manipulating various sizes in order to get the proper softening so that a uniform joint may be obtained upon blowing. There are now several types of burners on the market which are quite efficient in handling Pyrex glass. One, a regular blast lamp with a third inlet for oxygen, is preferable, as it enables the worker to heat the part which is to be worked more uniformly by the air blast before adding the oxygen for the final softening. If acetylene is available, it can be used with compressed air in an ordinary glass-blowing lamp for working Pyrex glass. If a gas-oxygen or oxyacetylene flame is used alone, it will quickly soften this tubing, but the glass is liable to be strained, in which case the object has to be re-annealed. In using a burner of the inlet type, it is very desirable that the cylinder containing the compressed oxygen be supplied with a pressure regulator, so that the amount of oxygen introduced into the burner can be properly controlled. Warning! No oil or grease should be used for the lubrication of the stop cock or regulator.

Cross Fires.

Another type of burner used by glass blowers is known as the *cross fire*. Cross fires are particularly useful in heating tubing of large diameter and are standard equipment with the professional worker.

They consist of a series of special burners, arranged in two lines and facing each other, with from two to five burners on each side. A blast of air for each burner blows out, horizontally, a hot oxidizing flame, from 4 to 6 inches in length. The flames are adjusted so that they focus accurately on a piece of glass tubing held centrally between the burners. The arrangement is such that a substantial length of tubing can be uniformly heated from both sides as it is rotated in the cross fires.

The Work Table.

If much glass blowing is to be done, it will pay to arrange a special work table. The top should be covered with asbestos board, which has the advantage over wood of not charring in contact with hot glass. Glass dropped on asbestos board is not so likely to break as on stone. The lamp should be permanently mounted near the front edge, with gas and air connections coming through from beneath the table. It will be found very convenient to have a meter stick mounted along the front edge of the table for use in measuring tubing. Racks or holders for the glass-working tools should be provided at the side or back of the table. Finally, a can should be provided as the last resting place for waste ends of glass and misguided efforts.

Glass blowing should be done in a good light but preferably not in direct sunlight. The operator should be seated in a chair or on a stool of such height that when working he may comfortably rest one or both elbows on the table. The comfort of the operator has a decided influence on the character of his

work, especially in the case of a beginner, who often defeats his purpose by assuming uncomfortable or strained positions. Steadiness and exact control of both hands are essential in most operations; any uncomfortable or strained position tires the muscles and weakens the control of the operator over them.

Arrangement of Exercises.

In the arrangement of the exercises here presented, several factors have been considered. It is important that the first exercises be simple, although not necessarily the simplest, and they should teach the fundamental operations which will be used and amplified later. They should, in themselves, be things which are of importance and commonly used in glass work, and they should be so arranged that the fundamental points, such as the rotation of glass, the proper temperature, blowing and shrinking the glass, may be learned with a minimum expenditure of time and glass. It is, therefore, recommended that the beginner take them up in the order given, at least as far as No. 7, and that each be mastered before attempting the next. The beginner should not leave the first exercise, for example, until he can join together two pieces of tubing so that they form one piece of substantially uniform inner and outer diameter and without thick or thin spots. From two to four practice periods of 2 hours each should suffice for this.

The manipulation of Pyrex glass requires much the same technique as does the working of lime-soda glass. The outstanding characteristics of Pyrex glass in contradistinction to lime-soda glass are: its resist-

ance to sudden changes in temperature, its high softening temperature, and its quickness of setting when removed from the flame. The beginner will find that there is a marked difference in the behavior of soft glass and of Pyrex glass. Once the manipulation of soft glass is learned, however, the blowing of Pyrex glass is very simple, and, in fact, the manufacture of many pieces of apparatus is easier with Pyrex glass than with soft glass because of the low coefficient of expansion of the former and its resistance to sudden heating and cooling.

This chapter and the following one, also, should be frequently read over, as many of the points discussed will not be understood at first and many of the manipulations described will not be necessary in the simpler exercises.

CHAPTER II

GENERAL OPERATIONS

Cleaning the Glass.

Successful glass blowing requires the use of clean tubing. Glass which has accumulated dust and dirt should not be used without cleaning. Generally, this can be accomplished by drawing or pushing a wet or damp cloth through the tube if it is large enough. Where a more drastic cleaning agent is required, the commonly used mixture of potassium dichromate and sulphuric acid can be employed. Tubing of small diameter is not so likely to be dusty except at the end. A very handy tool for cleaning short lengths of small tubing is the wooden applicator used by doctors for holding cotton swabs. These are round, wooden sticks about $3/32$ inch in diameter and 6 inches long. With a small piece of absorbent cotton twisted around the end of the applicator, it can be used very effectively to clean out small tubing. For large-size tubing, tissue paper or cotton wound round a wooden dowel can be employed. The use of wire or metal of any kind should be avoided, as it might scratch the glass. The ordinary bristle brush mounted on wires is a source of danger, in this respect. It is convenient to keep on hand a supply of clean tubing of the commonly used sizes; the inside can be kept from accumulating dust by closing each end with a tuft of cotton.

Cutting Soft Glass.

For this purpose, a *glass knife* is preferred to a file, if the glass is cold; if it is hot, a file must always be used, and its edge slightly moistened to prevent drawing the temper. The glass knife is simply a flat piece of hard steel, with the edges ground sharp on an emery wheel. The bevel of the edge should be from 30 to 60 degrees. An old flat file can easily be ground into a suitable knife. The glass knife makes a narrower scratch than the file but appears more likely to start the minute crack which is to cause the tube to break at that point, and the break is more likely to give a good square end. The scratch should be made by passing part of the knife or file once across the glass, never by "sawing" the tool back and forth. This latter procedure dulls the tool very quickly.

In breaking a piece of glass tubing, many persons forget that it is necessary to *pull* the ends apart, as well as to bend the tube very *slightly* in such a direction as to open up the minute crack started in the scratch. Care in breaking the tube is essential, as it is impossible to do as good work with uneven ends as with square ones.

When tubing of large diameter or thin wall is to be cut, it is often better not to attempt to break it in the usual way but to heat a very small globule of glass ($1/16$ to $1/8$ inch in diameter) to red heat and touch it to the scratch. This will usually start the crack around the tube; if it has not proceeded far enough, or has not gone in the desired direction, it may be led along with a hot point of glass. This is put a little beyond the end of the crack and, as the latter grows out toward it, moved along the path where the crack is

desired. This point of glass is also very useful in breaking off very short ends of tubes, where there is not room to get a firm enough hold and sufficient leverage to break the tube in the ordinary way, and for breaking tubes attached to large or heavy objects, which would be likely to make trouble if treated in the ordinary way.

Another way of cutting large tubing, especially if it has rather thick walls, is to make a scratch in the usual way, and then turn on the smallest and sharpest possible flame of the blast lamp. The tube is next taken in both hands and held horizontally above the flame so that the scratch is exactly over it. The tubing is now rotated rapidly about its axis and lowered so that the flame is just tangent to its lower side. After about 10 seconds of heating, it is removed from the flame and the hot portion quickly breathed upon, when it will generally crack apart very nicely. Care must be taken to hold the tube at right angles to the flame during the heating and to rotate it so that only a narrow strip of the circumference is heated, and the scratch should be in the center of this heated strip. By this means, tubing as large as 2 inches in diameter is readily broken.

Griffin's glass cutter, which contains a hardened-steel wheel, like that on any ordinary window-glass cutter, and a device by which this can be made to make a true cut clear around the tube, is a very handy article, especially for large tubing, and may be obtained from many dealers in chemical apparatus.

Cutting Pyrex Glass Tubing.

The cutting of Pyrex glass presents some difficulties, especially in the large sizes. Tubing up to about

1/2 inch in diameter can be cut quite readily by the usual method of scratching with a knife or file and then pulling apart with a slight bending movement. In the larger sizes, the low coefficient of expansion acts somewhat as a drawback to the use of a hot point of glass, and more drastic cutting methods must be employed.

One way to cut Pyrex tubing is as follows: First cut a fairly deep groove entirely around the tubing with a sharp file. A very convenient guide in cutting a true groove consists of a sheet of stiff paper wrapped around the tubing and held in place by a rubber band; the edge of the paper marks the place where the cut is to be made. After the groove is filed, heat it suddenly over most of its length by means of an electrically heated resistance wire. Sometimes this treatment is sufficient to crack the glass along the groove. If the glass does not crack, replace the wire and repeat the heating. Now remove the tubing from the heated wire and touch a drop of water to the groove. This should start a crack. In extreme cases, it is sometime necessary to turn a small stream of cold water from a wash bottle upon the heated groove in order to produce a crack.

The wire-cutting unit should be made from a loop of fairly heavy resistance wire and a suitable current regulating device and switch. There are many ways of arranging the resistance-wire unit. A tool made from hard rubber with binding posts at the end, which permit the resistance wire to be adjusted to the right length nearly to encircle the tube, has proven very useful. The arrangement is shown in Fig. 1. The tool is connected through a suitable rheostat to a

light socket. The circuit is completed by pressing the sides of the tool together. A few seconds' application

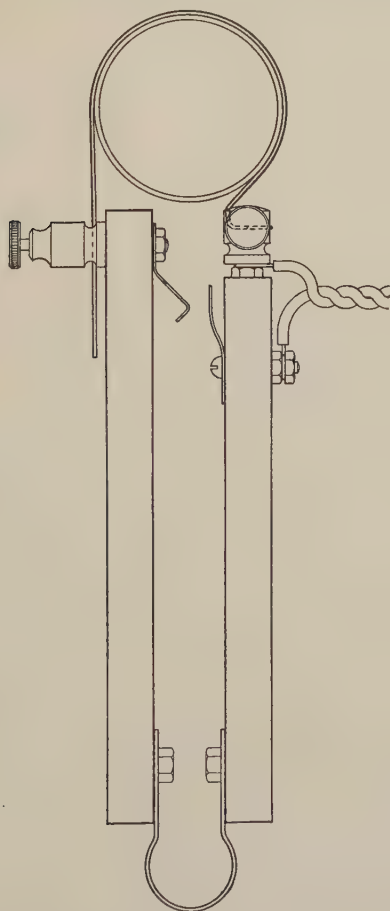


FIG. 1.—Handy hot wire glass-cutting tool. (*Suggested by Mr. Kraissl.*)

of this tool should be sufficient to start a crack along the filed grooves. This outfit is also very convenient for cutting large-size tubing of soft glass.

A "hot-wire" unit for mounting on a desk or table is shown in Fig. 2. The resistance wire is passed through two small holes near the end of the asbestos-board base and forms an adjustable loop. Beneath the board, one end of the wire is attached to a binding post, while the other end is weighted and hangs free so as to contract the loop to the size of any piece of tubing which may be inserted in it. A rheostat

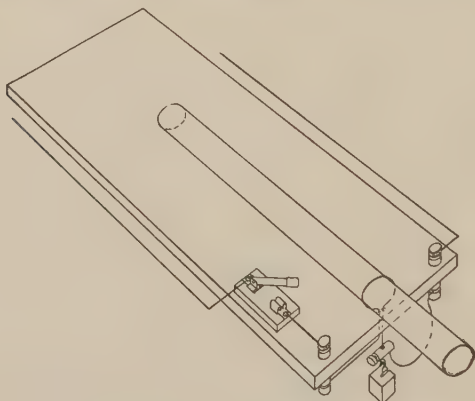


FIG. 2.—Hot wire glass-cutting unit for desk.

controls the current, and a switch is provided for opening and closing the circuit.

Another method of cutting Pyrex tubing consists of filing a groove around the glass, just as described in the previous paragraph. Next, cut some strips of blotting paper (paper towels do very nicely) 2 or 3 inches wide. Wrap these strips around the tube on each side of the filed groove and about $1/8$ to $1/4$ inch away from the groove. Thoroughly dampen these paper rolls with water. Heat the groove for a few moments in the sharp, pointed flame of the blast lamp. If a crack has

not yet started, turn a small stream of cold water from a wash bottle upon the groove. Repeat the procedure, if necessary. This severe treatment of Pyrex tubing is sometimes necessary, as it is very heat resistant.

Bending Glass.

Inasmuch as this is one of the commonest operations in the laboratory, it is assumed that the reader knows how to perform it. It should be noted, however, that in order to obtain the best results a broad (fish-tail burner) flame should generally be used, and the tube rotated on its axis during the heating and allowed to bend mostly by its own weight. If large tubing is to be bent, one end must be stoppered, and great care used. Whenever the tube shows signs of collapsing or becoming deformed, it must be gently blown out into shape, heating the desired spot locally, if necessary. A blast lamp is likely to be more useful here than the fish-tail burner.

Drawing Out a Tube.

Most students learn this the first day of their laboratory work in chemistry, but few take pains to do it well. The tube should be heated in the flame of a Bunsen burner or blast lamp (preferably the latter) until it is very soft. During this time, it must be continuously rotated about its axis and so held that the edges of the heated zone are sharply defined; *i.e.*, it should not be allowed to move back and forth along its own axis. When so hot that it cannot longer be held in shape, the tube is removed from the flame, and the ends slowly and regularly drawn apart, continuing

the rotation of the tube about its axis. By regulating the rate of drawing and the length of tube heated, the desired length and diameter of capillary may be obtained. The tube should always be rotated and kept in a straight line until the glass has set, so that the capillary may have the same axis as the main tube. This capillary or "tail" is often a very necessary handle in glass blowing and, if it is not straight and true, will continually make trouble.

In drawing out very large tubing, say, from 1 to 2 inches in diameter, it is often necessary to draw the tube in the flame, proceeding very slowly and at a lower temperature than would be used with small tubing. This is partly on account of the difficulty of heating large tubing uniformly to a high temperature and partly in order to prevent making the conical part of the tube too thin for subsequent operations.

Constricting a Tube.

Where a constriction is to be made in a tube, the above method must be modified, as the strength of the tube must be maintained, and the constricted portion is usually short. Small tubes are often constricted without materially changing their outside diameters, by a process of thickening the walls. The tube is heated before the blast lamp, rotating it about its axis, as later described, and, as it softens, is gradually pushed together so as to thicken the walls at the heated point, as in *a*, Fig. 3. When this operation has proceeded far enough, the tube is removed from the flame, and the ends cautiously and gently drawn apart, continuing the rotation of the tube about its axis and taking care not to draw too rapidly at first. The

resulting tube should have a uniform exterior diameter, as shown in *b* (Fig. 3).

This method of constriction is not suited to tubes much over 1/4 inch in diameter, since the mass of glass in the constricted part becomes so thick as to be difficult to handle when hot and likely to crack on cooling. Larger tubes are, therefore, constricted by heating in a narrow flame, with constant rotation, and, when soft, alternately gently pulling the ends apart and pushing them together, each motion being so regulated that the diameter of a short section of the tube is gradually reduced, while the thickness of the wall of the reduced portion remains the same as that of the rest of the tube or increases only slightly. This pulling and pushing of the glass takes place in the flame, while

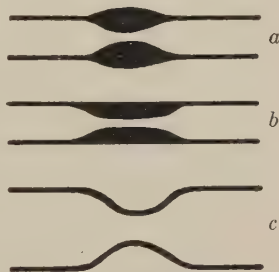


FIG. 3.—Constricting a tube.

the rotation is being continued regularly. The result may appear as indicated in *c* (Fig. 3). The strength of the work depends upon the thickness of the walls of the constricted portion, which should never be less than that in the main tube and, usually, a little greater. This operation is most successful with tubing having a relatively thin wall.

Flanging a Tube.

This operation produces the characteristic flange seen on test tubes, necks of flasks, etc., the object being twofold: to finish the end neatly and to strengthen it so that a cork may be inserted without breaking it.

This flanging may be done in several ways. In any case, the first operation is to cut the tube to a square end and then heat this end so that the extreme $1/16$ or $1/8$ inch of it is soft and begins to shrink. The

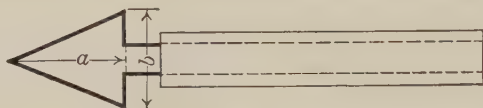


FIG. 4.—Flanging tool.

tube is, of course, rotated during this heating, which should take place in a flame of slightly greater diameter than the tube, if possible. The flange is now produced by expanding this softened part with some

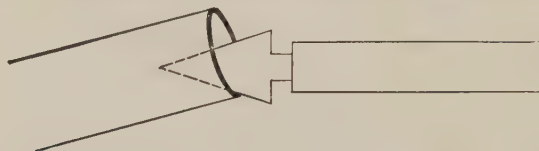


FIG. 5.—Flanging a tube with flanging tool.

suitable tool. A cone of charcoal has been recommended for this purpose and works fairly well, if made so that its height is about equal to the diameter of its base. The tube is rotated, and the cone, held



FIG. 6.—Flanging a tube with carbon rod or wire.

in the other hand, is pressed into the open end until the flange is formed. A pyramid with eight or ten sides would probably be better than the cone.

A better flanging tool is made from a triangular piece of copper, brass or, for working Pyrex tubing,

nickel, about $1/16$ inch thick, and mounted in a suitable handle. Such a tool is shown in Fig. 4, being cut from a sheet of copper and provided with a handle made by wrapping asbestos paper moistened with sodium-silicate solution around the shank of the tool. It is well to have several sizes and shapes of these tools, for different sizes of tubing. The two sizes most used will be those having about the following dimensions: (1) $a = 2$ inches, $b = 1$ inch; (2) $a = 1$ inch, $b = 1$ inch. When the end of the tube is softened, the tool is inserted at an angle, as indicated in Fig. 5, and pressed against the soft part, while the tube is quickly rotated about its axis. If the flange is insufficient, the operation may be repeated. The tool should always be warmed in the flame before use and, occasionally, greased by touching it to a piece of wax or paraffin. After the flange is complete, the end must be heated again to the softening temperature and cooled slowly, to prevent it from cracking.

Some glass blowers use a small carbon rod, about $3/16$ inch in diameter, as a flanging tool for tubes larger than about $3/8$ inch in diameter and a small iron wire or similar piece of metal for smaller tubes. In this case, the tube is heated as above described, and the rod or wire inserted in the end at an angle and pressed against the softened part, as indicated in Fig. 6, while

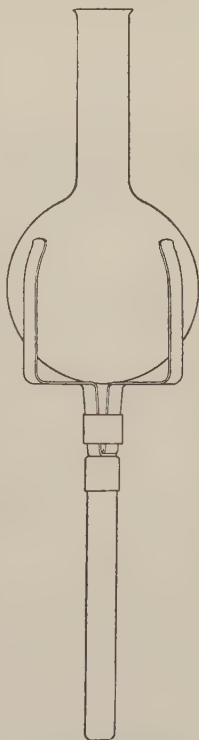


FIG. 7.—Holder for bulbs and flasks.

the tube is rotated about its axis. For large, heavy tubes, a larger carbon would be used. The carbon rod should also be greased before use, by warming it and touching it to a piece of beeswax.

Special Supports.

In working with tubing which is awkward to support and rotate, because of its shape or weight, special auxiliary supports are of great assistance.

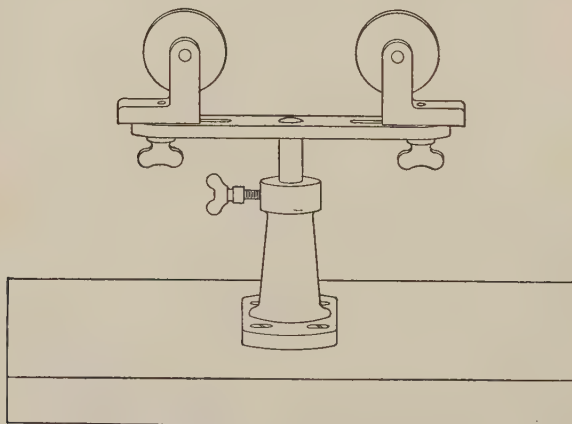


FIG. 8.—Adjustable support for long or heavy tubes. (*Suggested by Mr. F. Kraissl.*)

Figure 7 illustrates a holder for handling bulbs or flasks. It consists of a pair of fingers or clips, made of springy metal, which hold the bulb firmly; the bulb can then be rotated by means of a handle attached to the clips.

When heating long pieces of tubing, it is helpful to rest some part of the tube in a support of some kind. The simplest arrangement is a V-shaped notch in a board supported vertically on the table at the correct

height. A more elaborate support can be made by mounting two fiber wheels in a plane at right angles to the axis of the tube. The wheels are mounted adjustably, so that the tube will rest on their periphery while it is being rotated. Such a support is shown in Fig. 8.

Rotation of the Tube.

This is the fundamental manipulation in glass blowing, and upon it, more than all else, depends the uniformity and finish of the work and, often, the possibility of accomplishing the work at all. Directions for it will be given on the assumption that the reader is right-handed; if otherwise, the position of the hands is, of course, reversed. The object of rotation is to insure even heating of the whole circumference of the tube at the point of attack, to equalize the effect of gravity on the hot glass and prevent it from falling out of shape when soft, and to keep the parts of the tube on each side of the heated portion in the same straight line.

In rotating the tube, both hands must be used, so that the two ends may revolve at the same rate and the glass in the hot part not be twisted. The rotation is performed by the thumb and finger of each hand, the other fingers serving to support the tube. As it is almost always necessary to follow rotating and heating a tube by blowing it, the hands should be so placed that it will be easy to bring the right-hand end up to the mouth without shifting the hold on the glass. For this reason, the left hand grasps the glass with the palm down; and the right hand, with the palm turned toward the left. If there is any choice, the longer and

heavier part of the tube is usually given to the left hand, and it is planned to blow into the shorter end. This is because it is easier to support the tube with the hand which has the palm down. This support is accomplished by bending the hand at the wrist so that it points slightly downward and then curling the second, third, and little fingers in under the tube, which is held between them and the palm. This support should be loose enough so that the thumb and first finger can easily cause the tube to rotate regularly on its axis but firm enough to carry all the weight of the tube, leaving the thumb and first finger nothing to do but rotate it. The hand must be so turned, and the other fingers so bent, that the thumb and first finger stretch out nearly to their full length to grasp the tube comfortably.

The right hand is held with the palm toward the left, the fingers, except the first, slightly bent, and the tube held between the first finger and the thumb while it rests on the second finger and that portion of the hand between the base of the first finger and the thumb. Rotation of the tube is accomplished by rolling it between the thumbs and first fingers, the rotation being continued in the same direction regularly and not reversed. It is better to roll slowly and evenly, with a series of light touches each of which moves the tube a little, than to attempt to turn the tube a half a revolution or so with each motion of the hands. The hands must be held steady, and the tube must be under good control at all times, so that both ends may be rotated at the same angular velocity, even though they may be of different diameters, and the tube be neither drawn apart nor pushed together,

unless such a motion is expressly desired, as it sometimes is. The hot part of the glass must be constantly watched to see that it is uniformly rotated and not twisted nor pulled out or pushed together more than is desired. Care must also be taken to keep the parts of the tube in the same straight line or as near it as possible.

When flanging a tube, it is held and rotated with the left hand, as above described, while the right hand holds the flanging tool.

When part of the end of a tube must be heated, as in Exercise No. 6, and rotation must be very carefully performed and continued during the blowing, both hands are used. The right hand is held as above described; and the left hand, close to it and either as above described or else with the palm toward the right, grasping the tube in the same way as the right hand grasps it. This puts both hands in a position where the tube may be blown and rotated uniformly while its axis is kept horizontal.

Smoothness and exactness are the two things for which the beginner must constantly strive in glass blowing, and they are attained only by a careful attention to the details of manipulation, with a steady hand and a watchful eye. Every move must count, and the exercise must be finished with a minimum of reheating and retouching, for the best results.

CHAPTER III

ELEMENTARY EXERCISES

EXERCISE NO. 1

JOINING TWO PIECES OF TUBING END TO END— FIRST METHOD

This exercise is most easily learned on tubing with an exterior diameter of $1/4$ inch, or a little less, having moderately heavy walls. A piece of such

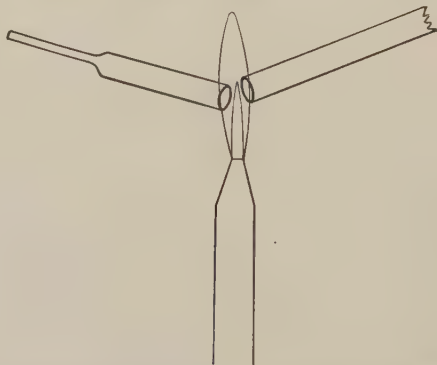


FIG. 9.—Softening ends of two pieces of tubing.

tubing is heated before the blowpipe at a point 10 or 12 inches from the end and there drawn out to a capillary as previously described (p. 21). The capillary is sealed off about 2 inches from the main tube, and the latter is cut near the middle. Instead of sealing off the tube with a capillary, the end can be

cut off square and temporarily closed with a small cork. Care should be taken to get square ends where the cut is made (p. 16). The flame is now so regulated that it is a little broader than the diameter of the tube, the sealed half of the tube taken in the left hand and the other half in the right. The open end of the sealed part and one of the ends of the other part are now held in opposite sides of the flame, inclined at a slight angle to one another, as indicated in Fig. 9, and rotated and heated until the surfaces of both ends are just softened. The two ends are then carefully and quickly brought together (*a*, Fig. 10), removed from the flame, and pulled apart a little, to reduce as much as possible the lump formed at the joint, as indicated in *b*. The joint is then tested by blowing into the open end of the tube to see if it is tight. If so, the flame is reduced to half or less than half of its former size, and the joint heated in it, holding the tube and continually rotating it, as directed in the last chapter (p. 27).

As the tube softens and tends to shrink, the two ends are pressed together a little and the walls allowed to thicken slightly, as in *c*. It is then quickly removed from the flame and gently blown, as indicated in *d*, continuing the rotation of the tube during the blowing, and at the same time pressing the ends of the tube together a little so as to make a *short* thick-walled bulb. The joint is then returned to the flame and reheated, rotating as before, shrinking to about the shape of *e*. When this stage is reached, the glass should be very hot and fluid, and the mass of hot glass thick enough to remain at its working temperature for about 5 seconds after removal from the

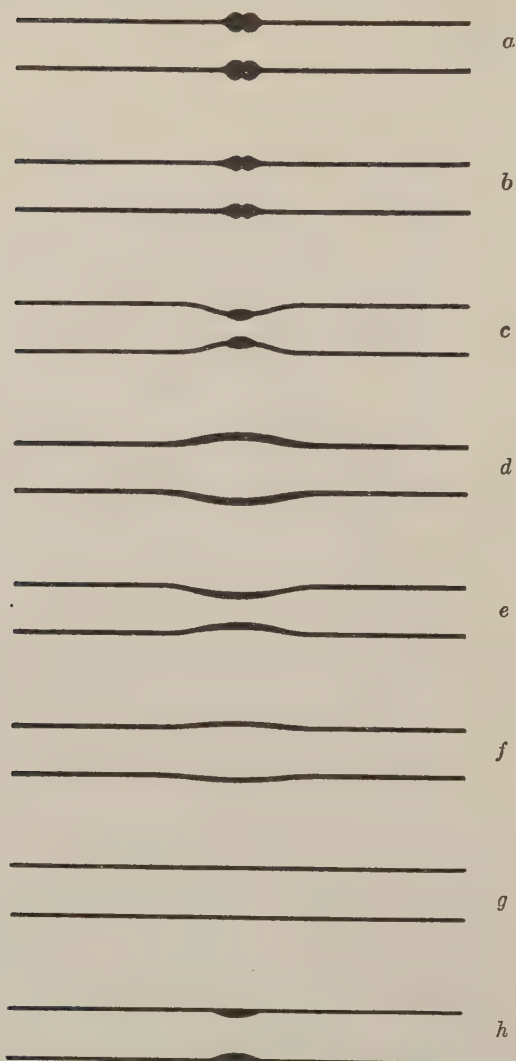


FIG. 10.—Joining two pieces of tubing end to end—first method.

flame. The glass is now reblown, as indicated in *f*, to form a flat bulb having walls of practically the same thickness as the original tube and only slightly larger in diameter. As soon as the tube is expanded, it is removed from the mouth, held horizontally in front of the worker, and gently drawn out to form one continuous tube, as indicated in *g*. During both the blowing and drawing of this bulb, the rotation must be continued, and both blowing and drawing must be carefully regulated so that the resulting tube may have the same internal and external diameter at the joint as elsewhere.

Discussion.

In making the original joint (*a*, Fig. 10), care should be taken that the lump formed is as small as possible, so that it may be entirely removed during the subsequent operations. For this reason, only the very tip ends of the two pieces of tubing are held in the flame, and the softening should not extend more than $1/16$ inch down the tube. As soon as the ends are sufficiently soft to stick together, they are made to do so. The first drawing of the tube *b* should take place immediately and reduce the lump as much as possible without making the adjacent walls of the tube thin. The whole purpose of the rest of the manipulation is to absorb or "iron out" the lump at the joint. For this reason, care is taken that this lump is always in the center of the flame while the joint is being heated, and a small flame is used so that little of the main tube may be softened. During the first shrinking of the joint *c*, the walls next the lump, being thinner than the lump is, reach

the softening temperature first and are thickened by the slight pushing together of the ends, so that they taper from the lump to the unchanged wall. Upon blowing this joint, these thickened walls blow out with the lump, but as they are thinnest next the unchanged tube, they stiffen there first. Then, as the thicker parts are still hot, these blow out more, and with the lump make a more or less uniform wall. By this first operation, most of the lump will have been removed, provided it was not too large at first and the tube was hot enough when it was blown. Beginners almost invariably have the glass too cool here and find difficulty in blowing out a satisfactory bulb. Under such circumstances, the lump will be scarcely affected by the operation.

During the shrinking of this bulb, the thinner parts, of course, are the first to reach the softening point and, thus, contract more than the thick parts, so that practically all of the lump can be absorbed, and a uniformly thickened part of the tube left, as in *e*. When this is just accomplished, the second expansion must be carried out quickly and the tube then drawn out as described, so as to reduce the tube to a uniform diameter. The tube is expanded only slightly in diameter, as shown at *f*. The drawing must proceed with care: Portions nearest the unchanged tubes are the first to reach the proper diameter and must be given time to just set at that point before the center of the bulb is finally drawn into shape. The drawing is, perhaps, best done intermittently in a series of quick pulls, each taking place as the thumbs and first fingers grasp the tube for a new turn in the rotation. If the tube is not

rotated during the blowing, the bulbs will be lopsided, and it will be impossible to get a joint of uniform wall thickness; if rotation is omitted during the drawing, the tube will, almost invariably, be quite crooked.

If the lump still shows distinctly after the operations described, the cross-section of the tube will be as in *h*, and the tube will be likely to break if ever reheated at this point after it becomes cold. The operations *d*, *e*, *f*, and *g* may be repeated upon it, and it may be possible to get it to come out all right.

Care must be taken not to blow the bulbs *d* and *f* too thin, as they then become very difficult to handle, and the joint is usually spoiled. The wall thickness of these bulbs must never be much less than that of the original tube. If the joint as completed has thinner walls than the rest of the tube, it will be more easily broken. It should be remembered that the length of the finished tube must be exactly the same as that of the original piece, if the walls of the joint are to be of their original thickness. The pushing together, therefore, during the two operations *c* and *d* must shorten the tube just as much as the final drawing (*f* to *g*) lengthens it.

The interval between the removal of the work from the flame and the beginning of the blowing must be made as short as possible, or else the portions next the main parts of the tube will set before they can be blown out and cause irregular shrunken areas.

EXERCISE NO. 2

JOINING TWO TUBES END TO END—SECOND
METHOD

The method described in Exercise No. 1 is very satisfactory for joining short lengths of straight tubing but becomes inconvenient or impossible when the pieces are long or bent, on account of the difficulty in uniformly rotating such work. In such cases, this second method is used. It does not usually give so smooth and pretty a joint as the first method, and it takes a little longer.

The joint is begun exactly as in the first method, and the manipulation is the same until after the preliminary tight joint (*b*, Fig. 10) is made. The flame is reduced, as usual, but instead of rotating the tube in the flame, only one part of the circumference is heated, and this is allowed to shrink thoroughly before blowing. It is then blown gently so that it becomes a slight swelling on the tube, and the operation repeated on an adjoining part of the joint. Three or four repetitions of the operation will usually cover the whole circumference of the joint in a small tube, the result being a swelling roughly similar to the first thick bulb in the first method (*d*, Fig. 10). If all the lumps of the original joint have not been removed by this operation, it may now be repeated upon such parts as may require it. The thickness of the wall in the bulb should be about the same as that in the original tube. The whole of the expanded joint is now heated as uniformly as may be, until soft enough so that it begins to shrink a little, and the swelling is gently drawn down to the same diameter as the main tube,

as in the first case. Any irregularities in the finished joint may be corrected by local reheating, shrinking, or blowing, as required.

Discussion.

In using this method, especially with larger sizes of tubing it is very important to keep the whole circumference of the joint hot enough during the operation so that it does not crack apart at the part which has not yet been worked. For that reason, the first heating, shrinking, and blowing should be performed as quickly as possible, leaving the resulting irregularities to be corrected later, rather than attempting to reblow the same part of the joint several times in succession until it is satisfactory. Care must be taken in this, as in the first method, that the blowing follows immediately upon the completion of the shrinking and removal of the object from the flame: Delay in blowing will cause shrunken places where the joint meets the original tubes, on account of the cooling and setting of the glass before it was blown. Most beginners err in being afraid to shrink the part of the joint enough before blowing it. On small tubing, the shrinkage may often extend so far that the inner surface of the shrunken part almost reaches the center of the tube. Insufficient shrinking results in failure to remove the lump formed at the original joint. It is often of advantage, after blowing out part of the joint, to allow that part a few seconds to set before going on with the rest, keeping the whole joint warm meanwhile in or near the smoky flame. This helps to prevent the twisting of the joint or

other distortion incident to the handling of a piece of work of awkward shape.

In making a joint on a very long or heavy piece, by this method, it is often advantageous to attach a piece of rubber tubing to the open end, hold the other end of this tubing in the mouth during the process, and blow through it, rather than attempt to bring the end of the glass up to the mouth. This enables one to keep closer watch on the joint and to avoid drawing it out or distorting it in handling. On the other hand, the rubber tube is an inconvenience on account of its weight and the consequent pull on the end of the apparatus and makes rotation difficult.

EXERCISE NO. 3

THE "TEE" TUBE

The operations involved are two: the blowing of a short side tube on a piece of tubing, and sealing another piece of tubing on this, by what is essentially the second method, as just described.

The two pieces of tubing to be used each have one end cut square and the other sealed in the usual manner. The longer of the two is now heated at the point at which the joint is to be made, until it begins to color the flame. A small flame is used, and the tube is rotated until the flame begins to be colored, when the rotation is stopped, and only one spot heated, until a spot the diameter of the tube to be sealed on has become red hot and begun to shrink. This is now gently blown out into a small bulb, as in *a* (Fig. 11) and it will be noted that this bulb will have walls tapering from the thick walls of the tube to a

very thin wall at the top. The sides of this bulb, below the dotted line, are to form the small side tube to which the main side tube is to be sealed. The top of the bulb is now softened by directing a small flame directly upon it, and as soon as it shrinks to the level indicated by the dotted line, it is removed from the flame and quickly blown out to form a thin bulb, as indicated in *b* (Fig. 11). This will usually be so very thin that a stroke of the file or glass-knife will break it off at the dotted line, leaving the side tube, to which the short piece of tubing is now sealed, according to the second method (Exercise No. 2). In doing this, care is taken to direct the flame partly on the main tube in the two crotches, so that both tubes blow out a little to give a filet, as indicated in *c* (Fig. 11), and, at the same time, increase the mechanical strength of the job. On the other hand, care is taken not to deform the main tube and not to produce such a bulge or bulb at the joint as will prevent the finished tube from lying flat on a table.

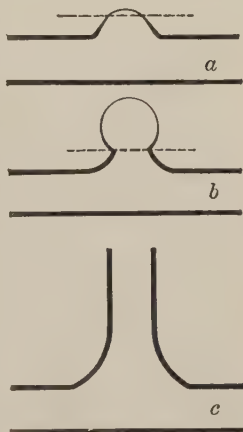


FIG. 11.—The "tee" tube.

Discussion.

Most beginners tend to err in the first steps of this operation by blowing too hard and too long when blowing out the little bulb. The result is a large, very thin bulb, which breaks off in such a way as to leave a hole in the main tube, occupying nearly half

the circumference of the tube at that point, instead of the neat side tube which should result. It is not difficult to seal a tube on this side tube, but is it very difficult to seal a tube into a hole in another tube. Care should be taken here, as in the two previous exercises, that the lump obtained at the joint when the two tubes are put together is made as small as possible and reduced, if possible, by gently drawing on the side tube as soon as the tubes have actually joined. It is much easier to prevent the formation of a lump at the joint than it is to remove the lump after it is formed. The remarks previously made about blowing quickly after removing the work from the flame apply here with especial force. A "tee" tube, from its very nature, is exposed to a good many strains, so care must be taken that the walls of the joint are of uniform thickness with the rest of the tube.

The beginner will find it easiest to make this tube out of two pieces of the same tube, about $1/4$ inch in diameter. Larger or smaller tubing is usually more difficult. If tubing much more than $1/4$ inch is used, the whole joint, including part of the main tube, must be heated nearly to the softening point at the close of the operation and well annealed, as described in Chap. I (p. 7), or it will be almost certain to crack. In the larger sizes of tube, it will be necessary to heat the whole circumference of the main tube frequently during the operation, to prevent it from cracking.

In sealing a small tube on the side of a large one, it is usually advisable, after warming the spot where the joint is to be made, to attach a small drop of glass to the tube at that point and direct the flame upon that, thus supplying, at the same time, both a definite point

to be heated and an extra supply of glass for the little side tube which is desired. In this way, it is also easier to blow out a side tube with a sufficiently small diameter. If the diameter of this tube should be much greater than that of the small tube, the latter may be enlarged with a carbon or a flanging tool.

EXERCISE NO. 4

TO JOIN TWO TUBES OF DIFFERENT DIAMETERS

In this case, the first method (Exercise No. 1) is to be used whenever possible, as it gives a much smoother joint than the second method. The directions given will describe the adaptation of this method to the problem; if the second method must be used on account of awkward shape, etc., of the work, the modifications required will be obvious to anyone who has learned to make the joint by the first method.

After sealing or corking one end of the larger tube, the other end is drawn out to form a tail, as described on page 21, taking care to have the tube uniformly heated and to draw the tail rapidly enough so that the cone is short, as indicated in *a* (Fig. 12). The tube is now rotated, a small flame directed against the cone at right angles to an element of it, and allowed to shrink a little, as indicated in *b* (Fig. 12) so that its walls will thicken. When the tail is cut off at the dotted line, the diameter of the opening and the thickness of the walls at that point should correspond with the dimensions of the tube to be sealed on. As the glass is hot, the scratch for cutting it must be made with a file (moisten the edge!), and often it will not break square across. Before pro-

ceeding to seal on the small tube, any large projections on the cut end are best removed by warming the cut surface a little, directing the small flame upon each projection in turn, and touching it with a warm scrap of glass. It will adhere to this and may then be removed by rotating this scrap a little so as to wind up the projection on it and then drawing it off, while the flame is still playing on the spot. This must be

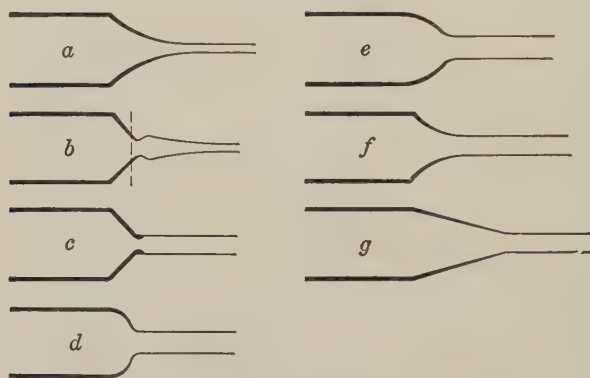


FIG. 12.—Joining two tubes of different diameters.

done rapidly and care taken not to soften the main part of the cone.

The large tube is now taken in the left hand, the small one in the right, and the ends heated and joined in the usual manner, taking care not to get at the joint a lump any larger than necessary. A small flame is now directed on the cone at right angles to its elements, as before, and the tube rotated so as to heat the whole circumference. The flame should be just large enough to heat the whole of the cone. As the latter shrinks, the lump at the joint is brought

into the edge of the flame and it and a very little of the small tube allowed to shrink with the cone.

When well shrunk and heated to blowing temperature, the joint is removed from the flame and blown gently, with careful rotation, pushing the tubes together a little when the blowing is about finished, so that the cone becomes a short, thick half-bulb, as shown in *d*, (Fig. 12). This corresponds to the first thick bulb in the first method (*d*, Fig. 10) and is treated similarly. It is again heated and shrunk, taking care not to involve either the large tube or the small one in the shrinking, blown quickly to about the same shape as before (*d*, Fig. 12), and then gently drawn out into a smooth cone *e*, exactly as in the first exercise. Care should be taken not to draw too rapidly nor too far, as then the resulting cone *f* is weaker than it should be and does not look well.

Discussion.

The beginner will find that this operation is best learned on two tubes which are not too nearly of the same diameter. A tube about $5/8$ inch in diameter and one a little less than $1/4$ inch will be suitable. Both should have moderately heavy walls ($1/16$ inch or a trifle over for the large tube, and a trifle less for the small one), but the large tube should not be too heavy, or else it will be hard to prevent melting down too much of the small tube and getting this drawn out too thin during the process. One of the troublesome features of this exercise is the difficulty of rotating two tubes of different diameters with the same angular velocity, so as not to twist the joint. Another difficulty is found in getting the cone uniformly

heated to blowing temperature without overheating and overshrinking the small tube. The reason for this is obviously the much greater circumference of the cone, especially at its large end, so that relatively much less of it is being heated at any time. The beginner is also inclined to start with a too-long cone or else heat so much of the large tube that part of its glass is included in the cone, with the result that, in order to get the right wall thickness, the cone must be made too long (*g*, Fig. 12). This does not look well and, usually, will be irregular in shape.

EXERCISE NO. 5

TUBE FOR CONDENSING SULPHUR DIOXIDE

This is useful as a test of mastery of the preceding exercise. A piece of 3/16- or 7/32-inch tubing is



FIG. 13.—Tube for condensing sulphur dioxide.

joined to each end of a piece of tubing 5/8 by about 5 inches, and two constrictions made in the large tube, by the method described on page 23. The small tubes are then bent in the same plane, as shown, and their ends fire-polished (Fig. 13).

EXERCISE NO. 6

BULB AT THE END OF A TUBE

For this exercise, tubing of 1/4-inch diameter and moderately strong walls is selected. A tail is drawn

out on one end of the tube, and a piece of tubing about 9 or 10 inches long is cut off. The tail should be carefully drawn in the axis of the tube and in the same straight line with it, as it is to be used as a handle in assembling the glass for the bulb. This tail must be long enough so that it can be conveniently held in the left hand, as described on page 27, and rotated about the same axis as the main tube. Holding the main tube in the right hand and the tail in the left, the tube is rotated in a large flame so that a piece of it, beginning where the tail stops and extending about an inch to the right, may be uniformly heated to the highest temperature at which it can be kept in shape. As soon as this temperature is reached, the tube is removed from the flame, continuing the rotation and taking care not to draw out the heated part, and gently blown. The rotation is carefully continued during the blowing, holding the tube in approximately a horizontal position. As soon as the tube has expanded a little, the tail is pushed gently toward the main tube, continuing the gentle blowing. If this is properly done, the heated piece of tube will become a short bulb about double its original diameter and about the same wall thickness as the original tube. It will have somewhat the appearance of *a* (Fig. 14) when properly manipulated.

The tube is now reheated as before, taking care, this time, that the heating extends over all that part of the bulb to the right of the dotted line in the figure, as well as part of the main tube adjoining. If this heating has been properly placed, when the operation of blowing and pushing together is repeated the result will be to lengthen the bulb into a uniform

cylinder, as shown in *b* (Fig. 14). Otherwise, the result will be a series of bulbs, as in *c* (Fig. 14) separated by thickened ridges which will be almost impossible to remove later and will disfigure the final bulb. This operation of heating, blowing, and pushing

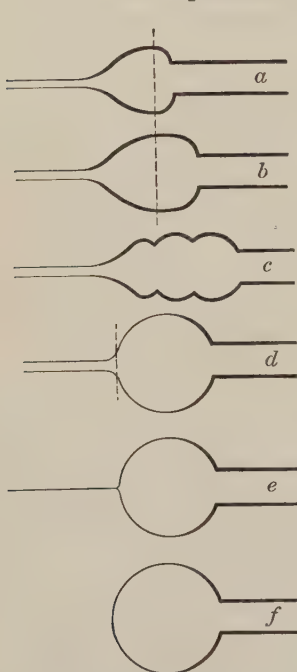


FIG. 14.—Blowing a bulb on the end of a tube.

ing together is repeated several times, until the cylinder becomes as long as can be conveniently handled (about 1 1/4 to 1 1/2 inches). If more glass is needed than is then contained in the cylinder, the latter may now be heated as a whole and blown and pushed gently into a shorter cylinder of a slightly greater diameter, and more glass then added as before.

When enough glass has been collected for the bulb, it is all well heated and blown gently a couple of times, pushing the mass together, as required, until a thick bulb like *d* (Fig. 14) is obtained. The tail must now be removed at the point indicated by the dotted

line. To do this, a very fine flame is directed on the point where the tail joins the bulb, and the tube well rotated as the glass softens at that point. When sufficiently soft, the work is raised a little, so that the flame instead of striking the glass squarely at the point indicated passes below and tangential to it. The

tail is now drawn off slowly, continuing the rotation, raising the work just out of the flame whenever the thread of glass drawn off becomes too thin, and lowering it again to the point where the flame just touches it when the glass stiffens a little. By this means, the tail may be drawn off without leaving an appreciable lump behind, as indicated in *e* and *f* (Fig. 14). When as much of the extra glass has been removed as is practicable, the flame is brought to play squarely upon the little lump left, the last of the tail removed, and the lump heated and gently blown to a small excrescence on the main bulb. The whole end of the latter is now heated until it begins to shrink a little and gently blown to make it uniform in thickness. The whole bulb is then heated in a flame of the proper size, so that it all may shrink to about two-thirds of its diameter. The flame must be very carefully chosen and directed, so as to shrink all the bulb, right up to the main tube, but not soften the latter. As soon as this stage is reached, the bulb is removed from the flame, continuing the even rotation, and blown to the desired size, preferably by a series of gentle puffs following one another at very short intervals. During the blowing, the main tube is held in a horizontal position, and any tendency of the bulb to fall out of line is corrected by the rotation. If the shape of the bulb or its size is not satisfactory, it may be shrunk again and reblown. Such shrinking should begin in a large, yellow flame, with just enough air to give it direction. The amount of air may be gradually increased as the bulb shrinks and the walls become thick enough to bear it without collapsing. If the bulb starts to collapse at any time, it must be immedi-

ately blown enough to regain its convex surface, before the shrinking proceeds further.

Discussion.

In collecting the glass for the bulb, enough must be gathered to give the walls the desired strength. Since the area of a sphere is proportional to the cube of its diameter, it is evident that doubling the size of a bulb diminishes the thickness of its walls to a very large extent. The limit of diameter for a strong bulb on ordinary $1/4$ -inch tubing, collecting the glass as above, is about $1\ 1/2$ inches, and the beginner will do well not to blow his bulbs more than 1 inch in diameter.

The collection of the glass is one of the most important parts of the process. If the mass of glass be twisted, furrowed or ridged, or lopsided, it is very difficult to get a good, even, spherical bulb, no matter how many times it is shrunk and blown. The greatest care should, therefore, be taken to get a uniform cylinder, on the same axis as the main tube; and to this end, the rotation of the tube must be carried on very evenly. For method of holding the tube, see page 28.

If a very large bulb is required, it will often be economical to seal on the end of the tube a short piece of a large tube, provided with the proper tail, and use the glass in the large tube for the bulb, instead of attempting to collect it from the small tube. In this case, part of the small tube will usually be included in the bulb, so that the joint comes in the latter and not where it joins the tube. As the amount of glass carried on the end of the tube increases in

weight and size, the difficulties of heating it uniformly, keeping it in the proper position, and handling it increase rapidly.

In collecting glass, it is usually best not to leave the part of the cylinder next the tube with too-thick walls. This is always the coolest part during the preparation for blowing the bulb; consequently, it does not get blown out and causes an ugly, thickened appearance on that end of the bulb.

If the bulb grows too long or pear shaped, it may be easily shortened by heating to the blowing temperature and then blowing gently, with the main tube in a vertical position and the bulb at the top of it. Gravity will then shorten the bulb nicely.

The finished bulb should be a nearly perfect sphere, with the axis of the tube passing through its center, and the portion of the tube adjoining the bulb must not be distorted, twisted, or blown out. In order to prevent the distortion of the tube, care must be taken that it is never heated quite to its softening point during the process.

EXERCISE NO. 7

BLOWING A BULB IN A TUBE

The tube is selected and one end closed, as in the previous exercise, but it should be cut a little longer, say about 12 inches. Beginning at a point about 4 inches from the closed end, glass is collected and blown into a thick-walled bulb, exactly as in the previous exercise. Greater care must be taken, however, that the cylinder collected and this thick bulb are of uniform thickness and set squarely in the axis of the

tube. Instead of removing the tail, the bulb must be blown, in this case, with both pieces of tubing attached, and care must be taken that they "line up" properly, *i.e.*, are in the same straight line, and that this line passes as near as may be through the center of the bulb. The tube is held in approximately horizontal position during the blowing of the bulb, as in the previous case, and especial care taken with the rotation. Both pieces of tube must, of course, be rotated at the same rate, and their softened ends must be kept at exactly the proper distance from each other, so that the bulb may be spherical and not elongated. If the blowing of the bulb be quickly and accurately done, it may usually be completed before the glass is quite set, and the alignment of the two tubes may then be rectified while looking straight through the bore of the tube.

Discussion.

The two points of greatest importance are the collection of the glass and the uniform rotation of the tube. A larger tube may be sealed in the middle of a small one when a large amount of glass is necessary. The piece of tubing used for the exercise must be long enough so that the fingers may be kept on a cool part of the glass without getting uncomfortably near the ends of the tube. It should not be any longer than necessary, however, as the extra weight and length make the manipulation of the hot glass more difficult.

When a string of bulbs are required on the same tube, a piece of glass 18 inches long may be used at the start, and the first bulb made near the closed end, as described. Each succeeding bulb will then be in

plain view during the blowing, and when the open end becomes too short for comfort, it may be dried out, cut off, and another piece joined to it, starting as in the first method (Exercise No. 1), but instead of drawing out the thick bulb to a tube, it is made part of the glass collected for the next bulb. If the string of bulbs becomes awkward to handle on account of its length and weight, it may be made in several parts and these later sealed together by the second method, preferably blowing through a rubber tube attached to the open end, as described on page 38.

Very neat small bulbs may be made on tubing of a diameter of $3/16$ inch or a little less, but the beginner is advised to start with tubing of about $1/4$ inch diameter. The use of tubing with too-thick walls usually produces bulbs which are thick walled at the point where they leave the tube but inclined to be too thin at the point of maximum diameter (perpendicular to the axis of the tube), where most of the strain comes, and strength is particularly needed.

CHAPTER IV

ADVANCED EXERCISES

EXERCISE NO. 8

SEALING A TUBE THROUGH ANOTHER TUBE

First Method—Making a Gas-washing Tube.

This first method can be used whenever one can work through an open end opposite to the end of the tube where the joint is to be made. To illustrate it, take a piece of rather thin-walled tubing, about $\frac{3}{4}$ inch in diameter, and some pieces of rather strong tubing a little less than $\frac{1}{4}$ inch in diameter. Draw off the large tube in a short cone, then draw off the tail as in the making of the bulb on the end of the tube, blow out the little lump slightly, shrink the whole cone a little, and blow gently to form a rounded end like that on a test-tube, with walls about the thickness of those of the rest of the tube. Cut this tube to a suitable length, say about 6 inches, and provide two corks which will fit the open end of it. Now cut a piece of the small tubing of the proper length to form the piece which is to be inside the large tube. For practice purposes, this piece should be about an inch shorter than the large tube. Flange one end of this tube a little, and anneal the flange well in the smoky flame. Bore one of the corks so that a piece of the small tubing will fit it, and cut a couple of notches in the side of this cork so that air can pass between it and

the glass. Pass a short piece of the small tubing through this cork, and attach the flanged piece of small tube to this by means of a short piece of rubber tubing, so that, when the whole is inserted in the large tube, it is arranged as in *a* (Fig. 15). The piece of glass tubing projecting out through the cork is now cut off so as to leave an end about $1\frac{1}{2}$ inch long when

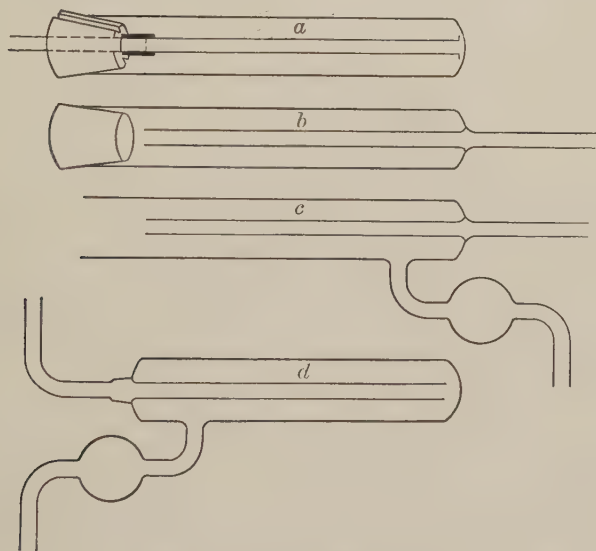


FIG. 15.—Gas-washing tube.

the cork is firmly seated, and the inner tube pushed into contact with the center of the end of the large tube, as shown in the drawing. Care should be taken that the little rubber tube which joins the two pieces is arranged as in the figure, *i.e.*, most of it on the piece of tubing which passes through the cork, and very little on the other piece, so that when the cork is removed after the small tube has been sealed through

the large one, the rubber tube may easily come with it. Select a short piece of the small tubing, of suitable length for the piece which is to be on the outside of the large tube as a continuation of the piece inside, and another piece for the delivery tube. A small bulb may be blown in the latter at a point about $2\frac{1}{2}$ inches from the closed end, and the open end cut off about $1\frac{1}{2}$ inches from the bulb. A cork or cork boring of suitable size to stopper the small tube is prepared and laid ready with the other (unbored) cork for the large tube.

When everything is in readiness, the rounded end of the large tube is slowly heated until it softens and joins firmly to the small tube inside. After it has shrunk down well, it is blown out to its original size, by placing the whole end of the large tube, cork and all, in the mouth. Now, with a fine-pointed flame, the glass covering the end of the small tube is heated to the softening temperature and then is blown out to an excrescence by blowing on the end of the small tube which passes through the cork. The end of this excrescence is heated and blown off, in the usual way, so as to leave the small tube sealed on the inside of the large one and opening through it into this short tube which has been blown out. The end of the small tube which passes through the cork is now closed with the cork prepared for it, and the short outer tube is joined to the tube which has just been blown out, so that the joint appears like *b* (Fig. 15). Use the first method (Exercise No. 1) for this joint. Reheat the whole of the end of the tube nearly to the softening temperature, anneal it a little, and allow to cool a few seconds until well set. Now, remove cork, short

glass tube, and rubber tube from the open end of the large tube, and insert the solid cork in their place. Warm the joint and the whole of that end of the tube again carefully up to about the softening point, then seal on the side tube for the delivery of the gas, in the usual way, taking care that the whole of the end and the joint are kept warm meanwhile. When thoroughly sealed, the delivery tube is bent up parallel to the tube through which the gas enters and then out at right angles to it, as shown in *c*. The whole of the end of the tube is now cautiously reheated and then cooled slowly to anneal it.

The cork may now be removed from the open end of the large tube, this end heated in a large flame, caught together with a scrap of glass tubing, and drawn off into a cone, so that the base of the cone is about opposite the end of the inner tube. The lump of glass is drawn off the point of this cone, and it is reblown to form a rounded end, as previously described.

After this cools, the tube through which the gas enters may be heated at the proper point and bent at right angles to form the finished apparatus, as shown in *d*. The ends of the small tube are cut off square and fire-polished.

Discussion.

After the joint has once been made, great care must be taken to keep it hot during all the subsequent manipulations; and if it becomes somewhat cool at any time, it must be reheated very slowly. It is obvious that the rate of heating and cooling of the inner tube will be slower than that of the outer tube,

and this will readily produce stresses which tend to crack the tube at the joint. The amount of heating and cooling which such a joint will stand depends upon its form. The beginner should examine such a joint on regular factory-made apparatus and note the uniformity of wall thickness and the clean-cut appearance of the joint, as a model for his imitation. A ragged joint, where the line of joining of the inner and outer tubes wavers instead of going squarely around the tube, is almost sure to crack during the cooling and heating, unless extra precautions are taken with it. The presence of a small lump of glass at any point on the joint affords an excellent starting place for a crack, as do also the points on a ragged joint where the inner tube comes farther down on the outer tube than at other points.

In order to insure a joint which is square and not ragged, it is essential that the angle between the inner and outer tubes at the joint be very nearly a right angle. For this reason, the two tubes should not be of too nearly the same size, or, if this cannot be avoided, a small bulb should be blown on the end where the joint is to be made. If this bulb be made with the same wall thickness as the rest of the tube and somewhat pear shaped, it may be drawn out to the same size as the rest of the tube, if necessary, after the joint has been made.

This method is used wherever possible, in preference to the second method (Exercise No. 9), as it is easier to get a good joint with it. It may, also, be used where it is desired to seal the tube through the side of a tube or for a tube sealed through the wall of a bulb, as in a Geissler potash bulb or similar appa-

ratus. Where there is not space to join the inner tube to the blowing tube by a rubber tube, this joint may be made with a small piece of gummed paper, which can readily be broken when desired.

If the inner tube is quite long, the rubber tube connecting it to the blowing tube may not be strong enough to hold the inner tube rigidly, and, thus, the flanged end may move about and become displaced, especially just at the time when the rounded end of the large tube is being softened. If necessary, this movement can be prevented by placing a supporting cork some distance inside the large tube but far enough away from the rounded end so that the cork will not char when the rounded end is being heated in the flame. A convenient way to construct this support is to obtain a cork which just slides into the large tube snugly. Bore a hole through the center of the cork, so that it will slip over the small glass tube easily. Cut a couple of notches in the cork, so that air can pass it easily, and, finally, tie a couple of pieces of fine copper wire to the cork in such a manner that the cork can be withdrawn from the large tube when necessary by pulling upon the copper wires. When this is inserted in the large tube, the copper wires are tucked away just inside the end of the large tube, where they can be reached easily with the fingers or a pair of tweezers, at the proper time.

EXERCISE NO. 9

SEALING A TUBE THROUGH ANOTHER TUBE

Second Method—Making a Suction Pump.

Select a piece of tubing $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter, with walls about $\frac{1}{16}$ inch or a little less in thickness,

heat a place about 4 inches from one end, and draw it out so that when cut off at the proper point it will look like *a* (Fig. 16) the open end of the drawn-out part being small enough to slip inside another piece of the original tube. A small, thick-walled bulb is now blown, as indicated by the dotted lines, and annealed. A piece of the original tubing is now prepared, 7 or 8 inches long, with one end cut square off, and the other closed. A piece of 1/4-inch tubing, about 2 inches long and drawn out at one end to a tail several inches long, is also prepared, to form the

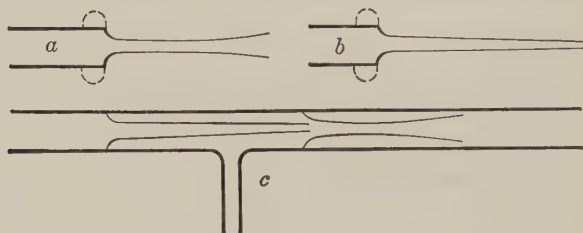


FIG. 16.—Suction pump.

inlet tube for the air. Another piece of the 3/8-inch tube is prepared, about 4 inches long, and provided with a tail drawn out, as indicated in *b*, so that, when cut off at about 2 1/2 or 3 inches from the main tube, its inner diameter may be slightly less than that of the narrowest point of the tube *a*. A small, thick-walled bulb is blown at the point indicated by the dotted lines and annealed. Care must be taken in drawing the capillary and blowing the bulb, in both *a* and *b*, that the capillary tubes are in the axis of the main tube and in the same straight line with it.

The open end of the 8-inch piece of tube and the bulb of the piece *a* are now warmed together, the end

of the tube only moderately and the bulb to about its softening temperature. The tube *a* is now inserted in the open end of the large tube, and the bulb softened with a suitable flame and pressed into good contact with the tube. It is then reheated, including the joint, blown a little, and pulled out to form a straight tube in line with the main tube. By warming the joint a little, and by proper rotation, the capillary may be brought into the same straight line with the rest of the tube.

Keeping this joint hot, a place about an inch from it on the tube *a* is warmed, and the piece of 1/4-inch tubing previously prepared is sealed on at that point. The joint is then well annealed and allowed to cool.

The tube *a* is now cut at such a place that when *b* is inserted in the open end the point will come near the end of the constriction of *a*, as shown in *c*. Care is taken to get a clean, square cut. The side tube is now cut off about an inch from the main tube and corked. Tube *b* is sealed into the open end of *a*, in the same way as *a* was sealed into the large tube, and the joint carefully annealed.

Discussion.

As in the first method, the secret of success lies in getting a square joint and having the inner tube leave the outer one at nearly right angles. All the remarks about annealing, lumps, etc., made under the previous method apply here.

This method may be applied in sealing a small tube into the end of a large one, the latter being either drawn to a cone and cut off at the desired diameter or else given a rounded end like a test-tube and

having a hole the proper size blown in the center of it. A suitable thick-walled bulb is to be blown on the small tube, as in the case described above. This method is also used in making the Kjeldahl trap *a*, (Fig. 17), the small tube to be inserted being first drawn, the thick bulb blown at its point of union with the main tube, and then the small tube bent and cut. The large bulb is best made with rather heavy

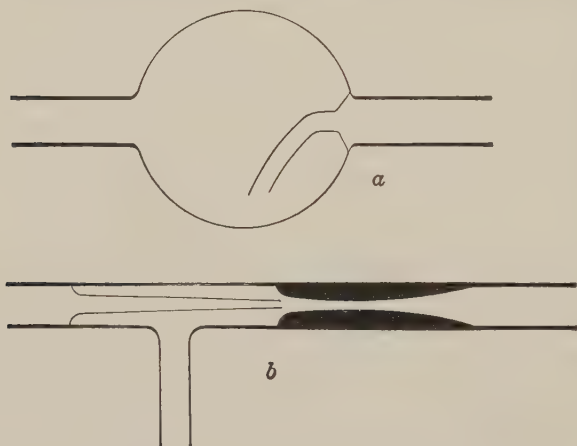


FIG. 17.—*a*, Kjeldahl trap; *b*, suction pump on smaller tubing.

wall, being either blown in the middle of a tube and one piece of the tube drawn or cut off or else made on the end of a tube. In the latter case, a drop of glass must be put on the point where the joint is to be, so as to get a hole of the proper size, with enough glass around it to prevent it from growing larger when it is heated. The authors prefer to blow the bulb in the middle of the tube, draw off one end of the bulb, and blow out the desired hole where the tube was drawn off. The whole bulb must generally be

reheated and blown a little at the end of the process and well annealed.

The suction pump can also be made on $1/4$ inch tubing, and one joint saved if desired, by constricting the tube to form the raceway for the water and air, as shown in *b* (Fig. 17) (see p. 22 for method), but it is more difficult to make a square joint on such small tubing.

CHAPTER V

MODIFIED METHODS AND SPECIAL OPERATIONS

CAPILLARY TUBING

This is commonly used in many forms of apparatus for gas analysis, and one is often called upon to join two pieces or to make a tee on it. The methods are nearly the same as with other tubing, except that more care and patience are required. The work must be done much more slowly, on account of the thickness

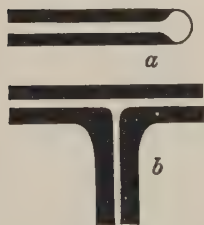


FIG. 18.—Capillary tubing.

of the walls, and open ends of the tube must always be enlarged before joining them to anything. This is best done by carefully sealing the end and then blowing, with several suitable reheatings, to form a pear-shaped bulb, as in *a*, (Fig. 18). The end of this is then heated and blown off, and the piece is ready to be joined to another similar end or to a piece of ordinary tubing, if desired. The joints are best not blown too much, as thick walls shrink very slowly. Much may be done by gently pushing the tube together or pulling it apart in the flame, to remove lumps and irregularities. It is necessary that the bore of the joint be approximately that of the main tube, and care must be taken that the latter is not constricted at the point where the joint begins.

Especial care must be taken to warm the tube slowly when starting and cool it slowly when through, as the thick walls frequently crack if not carefully handled. For this reason, the whole neighborhood of the joint must be heated somewhat, so that there may not be stresses set up between the heated and unheated portions.

In making the tee (*b*, Fig. 18), the inability to blow the joint makes itself decidedly felt, but if the side tube is properly enlarged, as previously described, a good joint can be made by alternately pulling and pushing on the end of the side tube and shrinking well.

Very fine capillary tubing should be blown with a rubber bulb instead of the mouth, so as not to get moisture into the tube. The rubber bulb may also be used to advantage on some of the coarser capillary tubing.

When a bulb is to be joined to a piece of capillary tubing, the joint is preferably made before blowing the bulb and will then be taken up a little way on the bulb during the process. Care must, of course, be taken not to constrict the capillary; the pear-shaped bulb blown on the end (*a*, Fig. 18) may well extend back a little farther than usual into the tube, so as to prevent this. If a bulb is required in the middle of a capillary tube, the latter is usually best cut and a piece of ordinary tubing of suitable size sealed in to provide material for the bulb.

GLASS ROD

Joints, tees, etc., in glass rod are made on the same principle as in tubing, except, of course, that they cannot be blown, and regularity must be obtained by

accumulating a small mass of uniformly heated glass and then drawing it to a suitable rod, on the same principle as Exercise No. 1.

Great care must be taken in heating and cooling this, as in the case of the capillary tubing and for the same reasons.

By joining pieces side by side, pressing with carbon plates or with a plate and a rod, and employing other suitable manipulations, stirrers, spatulas, and other objects may easily be made from rod, and its manipulation is relatively easy on account of the fact that one does not have to worry about the bore of the tube. But the same general rule about not having thick and thin spots in contact and making all changes in diameter on a taper, if possible, instead of abruptly, applies here. Thick pieces will cool and contract at different rates from thin ones, and cracks are likely to develop where they join. Work which has been formed with any tool must always be heated to the softening point afterward before allowing it to cool, in order to remove the stresses caused by the contact of the tool with the hot glass.

When it is necessary to join a piece of rod to the side of a piece of tubing, the end of the rod is made very hot while the wall of the tube at the spot desired is heated to just below the softening temperature. The rod can then be pressed into firm union with the tube and drawn a little to remove the excess of glass without deforming the tube.

TEMPORARY HANDLE FOR SHORT PIECES

It is sometimes necessary to seal a short piece of glass tubing or other short or small object to another

piece of glass. The principal difficulty is in finding some means of supporting and rotating the small object in the flame. The following method is often very convenient: As an auxiliary support, use a piece of glass tubing or glass rod, about 4 to 6 inches long, depending upon the size and kind of object to be sealed. This glass should be of the same lot and composition as the object. Hold the small object with a pair of steel forceps and gradually heat the end which is not going to be sealed, until it almost softens. In the meantime, gradually heat up the piece of glass tubing (or rod) until the glass is just soft. Now remove the object and the glass tubing from the flame and quickly push the soft end of the tubing against the heated part of the object. The two parts will stick but not flow together. Now cool this temporary joint very slowly. As the glass in this joint has not been worked or allowed to flow together, there is still a plane of weakness at the joint. This glass tubing is now used as a handle, and the object can be sealed to another piece of glass, in the usual manner. After the seal is complete and everything is cold, tap the end of the glass tubing rather smartly with an ordinary lead pencil or a small block of wood. The glass tubing will snap off at the plane of weakness where the two pieces of glass were temporarily stuck together. This completes the operation, unless there are objectionable rough spots on the end of the glass object. In that case, the end should be fire-polished, if possible.

MENDING STOP COCKS

Mending the Plug.

The plug of the stop cock occasionally falls out and is broken. If the break is in the main part of the plug, nothing can be done except to search for a spare plug of suitable size and grind it to fit, as described below. If only the little cross-piece at the end is broken off, it can easily be replaced. In most ordinary stop cocks, the plug is solid, but the little handle is hollow. What has been said above regarding care in heating and cooling glass rod applies with especial force here. It is usually best to wind the whole of the plug with several thicknesses of asbestos cord, leaving bare only the end where the handle is to be joined. This diminishes the danger of cracking the plug by too-rapid heating and, also, makes it more comfortable to hold. A piece of rather thick-walled tubing of suitable diameter is chosen, drawn out so as to have a suitable taper (taking care to heat enough of the tube so that the capillary tail has good wall thickness and strength), and then a corresponding taper is drawn to form the other side of the handle. The result is shown in *a* (Fig. 19). The capillary tail is now heated and bent back to form a handle which will be in the same straight line as the axis of the plug (*b*, Fig. 19), and the main part of the tube drawn off at the dotted line, making a neat seal at that point. The broken end of the plug is now slowly warmed in the smoky flame, the heat gradually increased by a gentle stream of air from the bellows, and the point at which this handle is to be attached finally brought to the temperature at which the glass flows freely. In the

meantime, the little handle has been warmed almost to the softening point. It is now quickly pushed into place (*c*, Fig. 19), taking care that its axis is parallel to the hole in the plug, and then drawn away from the plug just enough to make a graceful neck instead of the bulging one indicated by the arrow in the figure. With a fine-pointed flame, the little tail is now drawn

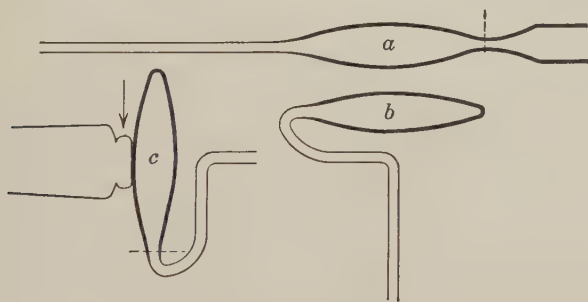


FIG. 19.—Stopcock plug.

off at the point indicated by the dotted line (*c*, Fig. 19), and the whole carefully annealed. If necessary, the handle can be blown a little before the tail is removed. Local heating and blowing at the point where the handle joins the plug is often necessary, in order to make a smooth job.

Regrinding.

This is sometimes necessary to make stop cocks tight, when the grinding has not been properly done in the factory. For this, a very little fine flour of emery or carborundum is the best and quickest. If this is not at hand, some clean sand may be ground in an agate mortar and, if possible, sieved. Only material which passes the 100-mesh sieve should be

used. It will be ground still finer in the process. For the final polishing, a little infusorial earth or even kaolin will do.

The surface to be ground is moistened with water and dusted over with a little of the abrasive. The plug is now inserted in the stop cock and turned with a gentle pressure. This turning should be in the same direction for several revolutions, then in the opposite direction for several more revolutions, etc. As the abrasive becomes finer during the grinding, a little more may be added, if necessary. In general, only a little grinding will be required, and one small pinch of carborundum or emery will be ample. The beginner usually grinds too much and with too-coarse material. As the grinding surface becomes dry, water is added drop by drop, and the grinding continued until the abrasive seems to be reduced to an impalpable powder, most of which has been squeezed out of the stop cock. The two surfaces in the stop cock are usually grinding upon each other at this stage, and inspection will show whether the contact between them is uniformly good. If not, the grinding must be continued with a little fresh abrasive. If contact appears to be good, the surfaces are ground together for a little with practically no abrasive, so as to polish them, and the joint is then washed out and tested.

In grinding in a new plug to replace a broken one, the plug selected should have practically the same taper as the seat into which it is to be ground and should be a very little too large. Care must be taken so to distribute the abrasive material as to grind mostly on the places where the plug fits tightly.

Sealing on a New Tube.

It frequently happens that one of the tubes of the stop cock is broken off close to the cock itself, and a new one must be joined to the stub of the old one. With care, this may often be successfully done even where the break is within $1/4$ inch of the stop cock. The first step is to clean and dry the stop cock, remove the plug, cork the open ends of the stop-cock sleeve and the other tube, and wind a couple of layers of asbestos cord carefully over the sleeve and the most of the corks which close it. A suitable tube, having, as nearly as possible, the same diameter and wall strength as the one broken off, is selected, and a piece the desired length cut off. The broken end of the tube on the stop cock is now squared off as well as possible, by cutting or by heating and drawing off the projections, and the new tube sealed on, usually with the first method (Exercise No. 1). If the break is very close to the stop cock, very little reheating and blowing can be done, on account of the danger of getting the stop-cock sleeve out of shape, and the work must be heated very slowly to prevent cracking. The main reliance is then placed on making a good joint when the tubes are brought together, and then drawing out this joint a little, at once, to get an even wall.

CLOSED CIRCUITS OF TUBING

In some pieces of apparatus, closed circuits of circular or rectangular shape are required. A similar problem is involved in apparatus like the ordinary Soxhlet extractor, where a small tube is joined to the side of a large one, bent to form a siphon, and attached

again to a continuation of the original large tube. The difficulty, in all such cases, is to provide for the contraction taking place as the last joint cools. If part of the circuit has the shape of the letter S or is a spiral, the natural springiness of the glass will take care of this. If not, the side of the circuit opposite to the joint and parallel to it must be heated, also, the two being finally heated together to the softening point, after the joint is completed, and then allowed to cool together.

To make the last joint, the rest of the tube is made in approximately the desired form, the two pieces which are to be joined to make the last joint being just enough out of the desired position to allow them to pass one another. The final joint is preferably made in the middle of a straight piece of tube, not at a tee. The two pieces which are to be joined are bent so as just to pass each other, marked at the right point with the glass-knife, and cut there, preferably with a small bead of hot glass. One or both of these tubes are now warmed to the softening point in such a place that the tubes can be made to meet properly, and the two cut ends pressed together. They are now warmed in the flame and joined together, either by simultaneously warming the opposite side of the circuit or some other suitable part, so as to allow the two ends to be pushed together again after they are softened, or by gently touching the places which do not unite with a hot bead of glass and using the glass to fill up the crack where the ends do not quite meet. Care must be taken not to leave knots or lumps of glass in the finished joint, and the latter should be well reblown and, if necessary, left as a small bulb or enlargement, rather than letting it have too-thick walls.

MAKING JOINTS AND REPAIRS ON APPARATUS

It is often necessary to make joints, additions, or repairs to large, bulky pieces of apparatus sometimes several feet in length and weighing several pounds. It is manifestly impossible to rotate such objects before the blast lamp, so the reverse operation is performed, and the blowtorch is rotated about the piece of apparatus. A very good blowpipe to use for this work is the hand-blast lamp or blowtorch made by dental-supply manufacturers. This is a light, convenient type torch. The blow torch should be connected to the gas- and air-supply taps by lightweight, flexible rubber tubing. The tubing should ordinarily be from 5 to 8 feet in length.

Numerous operations in glass blowing can be performed by the proper use of the hand blowtorch. For example, it is sometimes desirable to add another intake or outlet tube to a fixed piece of apparatus. First, protect the rest of the apparatus, wood mounting, etc., from the effects of the flame by wrapping or covering it with several pieces of asbestos paper. Next, connect a rubber tube for blowing to some convenient part of the apparatus, and be sure that all other air passageways are closed. It is frequently desirable to connect a calcium-chloride drying tube somewhere in the line of rubber tubing so as to prevent moisture from the breath being blown into the apparatus and condensing there. Now, gradually heat the tubing to be operated upon by twisting the torch about so that the flame rotates around the tubing, until the glass begins to color the flame. Then the rotation is stopped, and only one point is heated, until a spot the diameter of the tubing to be

sealed on has become hot and begun to shrink. This is now gently blown out into a small bulb. The top of the bulb is now softened by directing the flame upon it, and, as soon as it shrinks down, the flame is quickly removed and the glass is blown out to a very thin bulb. This thin bulb is removed by a stroke of the file. The open, squared end of the stoppered glass tubing which is to be sealed on is now held close to, but not quite touching, the projection around the hole just made. The flame is now rotated about the tubing until the glass at the end of the tubing and the edge of the hole are at just the right temperature. Then the flame is quickly removed, and the tubing is carefully but quickly pushed against the glass around the hole. The joint is now reheated by rotating the flame around it and blown as a unit, somewhat as described in the first method (Exercise No. 1), or worked by sections, as described in the second method (Exercise No. 2). With practice, a very neat joint can be made by this method.

Another common operation is the repairing of a broken tube in an apparatus. This may be done as follows: First, cut out the broken part, being careful to leave the ends of the remaining parts as square as possible. Next, cut and bend a piece of tubing so that it will just fit snugly between the two remaining ends of tubing on the apparatus. Fasten one end of the tubing to the apparatus in an airtight joint by means of a short piece of rubber tubing. Protect the apparatus, as mentioned before, by the use of asbestos paper. Support the other end of the glass tubing by hand, and gradually heat the joint by the hand blast, until the glass is the right temperature, when the

glass should flow together, since it is in contact. If it is not completely in contact all around, push the tube forward slightly and then pull it back to its original position. Blow the joint by either of the two methods. If the joint is in a rather inaccessible place, the second method will prove to be the most satisfactory one. Now, remove the rubber tubing from the remaining joint by pushing it down the glass tubing or cutting it off with an extremely sharp cutting instrument, such as a safety-razor blade. Heat this joint with the hand blast until the glass is the right temperature, when it should flow together nicely, if it is in contact all around. By alternately shrinking and gently blowing the glass, a smooth joint can be produced. It is not always possible to get a perfect square cut on the tubing to be repaired, so that it often happens that in this last operation the glass does not flow together all around the tubing. Have a piece of glass rod handy (about 1/16 inch in diameter), and, in case the glass does not flow together all around, apply the thin glass rod to the opening and allow the glass in the rod to flow in and fill up the remaining cracks. The diameter of the glass rod is just about right, so that it will soften sufficiently to flow quickly upon being introduced into the flame. Finish the joint by shrinking and reblowing, as described above.

SPIRALS

Spirals of glass tubing are probably best made freehand before the blowpipe, unless one has a great many of them to make and extreme accuracy is desired. To begin with, a piece of tubing of the

desired size (say $3/16$ inch in diameter) and a convenient length (about 2 feet) is selected, one end closed, and a right-angle bend made about 6 inches from the closed end. Holding the closed end in the left hand and the long, open one in the right, the spiral is begun. The short, closed end is to be parallel to the axis of the spiral and preferably in that axis. Using a moderate-sized flame, of somewhat yellow color, and taking care to heat the whole circumference of the tube, the long open end is wound

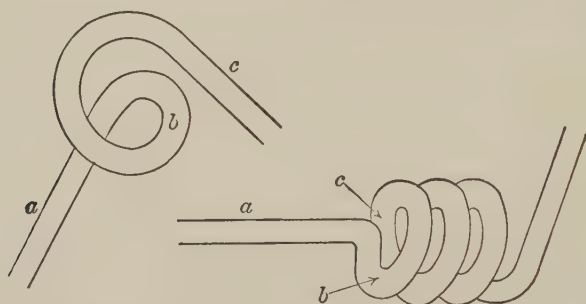


FIG. 20.—Making a spiral.

little by little into a spiral having the short end *a* (Fig. 20) as an axis. The bend at *b*, where the tube changes from the radius to the circumference of the circle, must be rather short, but the tube must not be flattened or constricted here. Especial pains are to be taken with the first turn of the spiral (*b* to *c*, Fig. 20), as the shape of this determines the diameter of the whole spiral and serves as a guide for the rest of the turns. The winding of the tube is best accomplished, after a portion has been softened, by slowly turning the short end *a* a little about its own axis, while the long, open end remains where it was. This

winds the tube into a spiral, just as if there were a solid cylinder in the center of it, and this cylinder were being turned about its axis and were winding up the soft glass upon its circumference. As the cylinder is not actually there, the curve of the turns must be carefully estimated by the eye, so that the spiral may be uniform and moderately smooth. When the original piece of tube has been used up, another piece is sealed on to the open end, and the operation continued as far as may be required.

CONE-AND-SOCKET JOINT

The cone-and-socket joint, sealed and fastened with wax or cement, is extremely useful in putting together apparatus which it is desired to disconnect frequently or occasionally, as the case may be. Such a joint is shown in Fig. 21e.

In constructing the socket part of the joint, it is necessary to have a carbon rod with a conical end having the exact taper desired in the socket. This can be made from an arc-light carbon by suitably turning it in a lathe, or it can be filed to the proper taper. The rod is finished by filing flat sides on the tapered part, so as to give it a polygonal cross-section (Fig. 21a). This shape gives a minimum area of contact with the heated glass when it is inserted and rotated therein.

A short length of 1/4-inch tubing is cut with a perfectly square end. The end is then heated to softness over a length of about 3/4 inch, while rotating in the flame of the blast lamp. The extreme end, which must be expanded the most, is heated the hottest. In the meantime, the carbon rod has been heated and

lubricated by rubbing against a piece of beeswax. When the glass tube is just at the right temperature, it is withdrawn from the flame, and the tapered carbon rod inserted. The carbon rod is pushed into the glass and simultaneously rotated, so as to expand

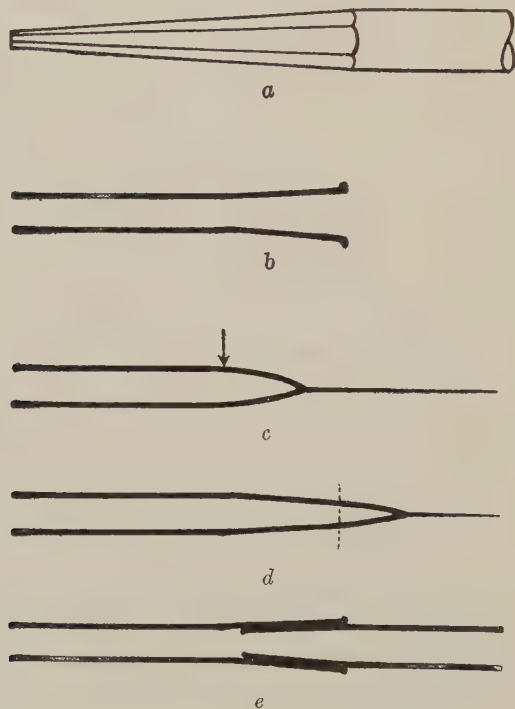


FIG. 21.—Cone and socket joint.

the end of the glass tube into a cone with the same taper as the carbon rod. Rotation of the rod gives the glass a circular cross-section. It will be found convenient to rotate the tube with the left hand in the opposite direction to which the rod is being rotated

with the right hand. The tube will usually become rigid before it can be given its final shape, because of the chilling effect of contact with the carbon rod. It can now be reheated and again rotated against the tapered rod to produce a socket of the proper length, as shown in *b* (Fig. 21).

It should be remembered, in making the socket, that the extreme end of the tube must be the softest, because it must be expanded most, and because the carbon rod touches it first and chills it most. If the rod is pushed in while the end is too cold, the glass tube will buckle and leave a wrinkle which it is difficult and usually impractical to eradicate. After the carbon rod has expanded the tube for a distance of about $3/8$ inch, however, little difficulty should be experienced in finishing the operation. Care should be taken to remove the tube from the flame and expand just as soon as it reaches the proper temperature. Otherwise, an excessively thick ring or rim of glass will be formed at the end of the tube, which may crack during subsequent heating when the seal is being made or opened.

In making the cone, another piece of $1/4$ -inch tube is rotated in the flame until quite soft and then quickly pulled apart so as to leave a very long and accurately centered tail of glass. It is quite important that this thread of glass, which is later to serve as a handle, be symmetrically attached to the tube. The tube is then reheated by directing the flame at the shoulder of the bend, as shown by the arrow in *c* (Fig. 21). When it is properly and uniformly softened, gently pulling on the thread of glass will pull the tube out into a uniform cone, as shown in *d* (Fig. 21). Some

little practice will be necessary to determine what length of the tube should be heated, in order to permit pulling it out into a straight-sided cone of the proper taper. It has been found convenient to use a Meker burner for this operation, as it provides a broader and more uniform heating zone than does the blast lamp. After cooling, the end is cut off, as indicated by the dotted line, in *d* (Fig. 21). The end is finished by fire-polishing.

The cone-and-socket ends can now be sealed to the apparatus for which they were intended, and the joint is ready for sealing.

Various kinds of wax or cement can be used in sealing the joint. For work at ordinary temperatures, the vacuum wax described in the appendix can be employed. The cone is warmed, and a thin film of the melted wax caused to flow onto it. It is then pressed into the warm socket, and the joint allowed to cool. Any excess of wax will be squeezed out and may be allowed to harden in place or wiped off. A final, gentle warming may be necessary uniformly to distribute the wax and finish the sealing operation. De Khotinsky cement can also be used as the sealing medium.

At any subsequent time, the joint may be pulled apart after warming with a very small flame. While warm, substantially all of the wax can be removed from the parts by wiping with a cloth. The last traces of wax are then removed by wiping with a cloth dampened with alcohol. A tuft of cotton on the end of a wooden applicator is useful in cleaning the inside of the socket. Glass apparatus which must be accurately weighed can be attached in this way

without introducing appreciable error due to making and breaking the seal.

GROUND JOINTS

It is sometimes desired to have a cone-and-socket joint with ground surfaces. The cone and socket can first be made as described in the preceding section. The cone should be straight sided and fit snugly into the socket. It can now be ground into the socket with emery or carborundum, as described in the paragraph on Regrinding, in the section, Mending Stop Cocks. If many such joints are to be made, it will pay to have a little sleeve of brass made with the proper taper to rough down the cone in it to the proper size, while the socket is roughed down by means of a brass or iron plug having the same taper. This prevents excessive grinding of one half of the joint in order to remove a defect in the other half and is the method commercially used in making stop cocks.

SMOOTHING AND SQUARING THE END OF GLASS TUBING

It is sometimes desirable and necessary to have the end of a piece of glass tubing square and smooth. This can be very readily accomplished by grinding in the following manner: Procure a piece of glass plate, either window glass or plate glass, of almost any convenient size—a piece 6 by 8 inches has proved very useful—and on the plate mix a watery paste of carborundum or emery and water. Square the end of the glass tubing by grinding it back and forth upon this glass plate, the carborundum or emery serving as the grinding medium. Faster work can be done by the employment of two glass plates.

About 80-mesh carborundum is used upon one for rough grinding, and about 150- to 200-mesh material is used upon the other plate for fine grinding. Hold the glass tubing in an upright position, and rotate it 30 to 60 degrees from time to time to insure uniform grinding. When the grinding is complete, wash the carborundum or emery off under a tap with running water, and then dry the tube thoroughly.

When a tube is cut or broken off with ragged edges remaining, it is frequently desirable to even it up as much as possible before sealing on another tube. By taking short strokes with the flat face of a file, across the sharp points and toward the axis of the tube, the points can usually be chipped off without starting a crack. Care should be taken, however, to push the file across the edge toward the center of the tube, as the reverse operation is likely to start a crack. Heating the tube somewhat before filing is helpful in preventing cracking.

If the jagged points are large, it may be more practical to heat them until soft and pull them off with another piece of glass.

SEALING VACUUM TUBES

Tubes which have been evacuated usually are sealed off while they are still connected to the vacuum pump. The connection should be through a small, rather thick-walled tube. When this is to be sealed, it is slowly heated toward the softening point. As the glass just begins to soften, the air-pressure will force it in, and care must be taken that the softening is uniform over the whole circumference of the tube.

As the shrinking goes on, the tube is gently drawn out to make a thick-walled cone at that place, and the end is drawn off as soon as the tube is sealed. The principal point to be guarded is the thickness of the walls of the cone, and uniform heating. A thin place or a hot place will give way under the air pressure and be sucked into the tube.

CLOSED TUBES FOR HEATING UNDER PRESSURE

Carius Method for Determination of the Halogens and Sulphur.

In this case, the tubing used must have thick walls (usually about $3/32$ inch) to withstand the pressure. Its external diameter is usually about $3/4$ inch. One length will usually make two tubes of standard length for the cannon furnace. Especial care must be taken in heating and cooling it, on account of the thick walls. A length is gradually warmed in the center, finally heated at that point until soft, drawn out, cut apart, and annealed. Taking one of the pieces, the cone is carefully heated and shrunk, as in Exercise 4, until its walls are as thick as those of the main tube. A flame with a little tinge of yellow should be used for this operation, to prevent devitrification (p. 5), as the thick glass shrinks slowly. The tail is now drawn off, and the whole end heated and gently blown several times to make a rounded end, like a test-tube, with walls as thick as those of the main tube. This must be carefully annealed. It is more important that the walls be thick than that the end be nicely rounded—it may, indeed, be left somewhat conical in shape.

At a point about 2 inches from the open end of the tube, it is slowly warmed and finally heated to the softening point. Grasping the open end with a pair of crucible tongs, it is cautiously pulled out, a little at a time, usually during rotation in the flame, to make a constriction of moderate wall thickness but of sufficient internal diameter to admit the tube containing the substance. After annealing this, cooling, and cleaning the tube, the acid and salt are introduced (the former by means of a long-stemmed funnel), and the tube is inclined and rotated about its axis so that the acid wets its surface about halfway up from the bottom. The substance is now weighed out in a piece of thin-walled glass tubing, closed at one end, and about 2 inches long. Inclining the large tube at a suitable angle, the small one is introduced, closed end first, and allowed to slide down the walls of the large tube until it reaches the place where the acid has wet the tube. Here it will stop, and if the tube is kept inclined during the rest of the operation, it will roll around inside the tube at this point and, thus, not get down where any acid is likely to get into it and produce any pressure by decomposing it before the open end of the tube is sealed. Now the tube is held in an inclined position, taking care that the acid does not reach up to the substance, and the constricted portion cautiously warmed and shrunk. It is finally shrunk and drawn out into a somewhat elongated cone, with walls as thick as the rest of the tube, and when this is accomplished, the end of the cone is sealed, and the waste piece drawn off. Anneal with great care, and cool in such a position that the acid cannot reach the hot glass. The shrinking of this cone takes a good deal

of patience and is one of the most important parts of the process. If the walls are left too thin, the tube may burst when heated, and the whole labor is lost. If care is taken, the same tube can be used for a number of determinations, until it becomes quite short.

SPECIAL GLASS-SEALING METHOD

This method¹ is particularly useful for sealing lenses into tubes, making colorimeter tubes with plane-glass faces, making plane-glass incandescent bulbs, etc. The objects which are to be joined together are heated in a special electric furnace to approximately their annealing temperature. The temperature should be sufficiently high so that the glass will not crack when an intense heat is applied to it. The flame from a small oxy-gas blowpipe is now passed rapidly over the junction of the two parts which are to be sealed together and while they are still in the furnace. Sufficient excess heat is applied so that the two glasses fuse together. By the rapid movement of the flame, complete fusion of the junction can be accomplished by this method, without propagating the stresses produced by this local heating beyond a restricted portion near the joint. Thus, this method can be used in constructing pieces of apparatus in which a slight deformation at the junction does not impair the usefulness of the apparatus. By the proper arrangement and choice of units, the electric furnace can be so constructed that it will heat and cool fairly rapidly. By this arrangement, the furnace can be so quickly heated that a small glass article can be raised to a temperature above the annealing temper-

¹ FAIRCHILD, C. O.: *J. Optical Soc. Am.*, **4**, 496-503 (1920).

ature, the junction completed by the application of the local flame, and cooling started before the glass has had sufficient time appreciably to change its shape. It is not absolutely essential that the two parts should be of the same kind of glass, and a perfect fit is likewise not essential. This method fails only for glasses which have too widely differing coefficients of expansion. The reader who is interested in making seals of this kind is referred to Mr. Fairchild's article for more complete details.

PYREX-TO-SOFT-GLASS JOINTS

Sometimes, certain parts of a particular installation, such as glass-diffusion vacuum pumps, mercury stills, etc. are constructed with Pyrex glass, while the remainder is constructed of soft glass. Also, it is sometimes necessary to have an all-glass connection between the various parts. It is impossible to fuse Pyrex laboratory glass and soft glass together directly, because of the great difference in their thermal expansivity. If, however, a sufficient number of glasses, each differing successively by small increments in its coefficient of expansion, are sealed together stepwise, it is possible to go from Pyrex to soft glass through such a series of intermediate seals.

The coefficients of expansion ($\times 10^6$) of certain glasses are approximately as follows: Pyrex laboratory glass, 3.2; Jena *geräte*, 5.0; soft glass, 8.5. It so happens that Jena *geräte* glass falls between Pyrex laboratory glass and soft glass in respect to expansivity, although it is closer to Pyrex glass than to soft glass. It also happens that Jena *geräte* will mix quite readily with both of these glasses.

To prepare the glasses for the intermediate seals, proceed as follows: Obtain some rod of small diameter (about 3/32 inch) of Pyrex glass, Jena *geräte*, and soft glass. Weigh out about 2 to 3 grams of each of the following mixtures:

1. Three parts Pyrex laboratory glass: 1 part Jena *geräte*

2. Two parts Pyrex laboratory glass: 2 parts Jena *geräte*

3. One part Pyrex laboratory glass: 3 parts Jena *geräte*

4. Jena *geräte*

5. Four parts Jena *geräte*: 1 part soft

6. Three parts Jena *geräte*: 2 parts soft

7. Two parts Jena *geräte*: 3 parts soft

8. One part Jena *geräte*: 4 parts soft.

Now, procure two pieces of heavy platinum wire. Take each mixture separately, melt it up in the blast-lamp flame, supporting the fused mass with the platinum wires. Pull it out into a rod, fold it over several times, remelt, and repull. This operation should resemble pulling taffy candy and has for its object the thorough and intimate mixing of the two kinds of glass. To start the melting and mixing operation, the bundle of rods of mixture No. 1, supported by the hands at each end, is heated at the center until well fused together. The heating is extended to either end, and the bundle twisted somewhat, as the heating progresses. When the flame nears the end, the platinum wire can be used to support the glass. Care should be taken during the mixing operation to entrap in the glass as little air as possible. It is impractical to crush, mix, and

remelt the glass because of the large number of air bubbles which would be incorporated by that method. Finally, pull the uniform mixture out into a glass rod about 1/16 inch in diameter. Repeat this procedure with each mixture, and carefully label each rod, so that no mix-up can occur. For convenience, the rods may be tagged Nos. 1 to 8 inclusive, No. 1 being the mixture of 3 parts Pyrex laboratory glass: 1 part Jena *geräte*; No. 4 being a pure Jena-*geräte* rod; and No. 8 being 1 part Jena *geräte*: 4 parts soft.

To make the joint, proceed as follows: Rotate one end of the Pyrex tube in the flame, the other end being closed with a small cork. Just as the Pyrex tube begins to soften, apply glass rod No. 1 to it and flow onto the end of the Pyrex tube a uniform ring of the No. 1 glass. Now, flow on a ring of No. 2 glass, and continue on up the line, finally sealing on a piece of soft-glass tubing after No. 8 has been applied. It is convenient to have before the operator a block of wood in which there are sixteen holes in pairs of two each in two rows. The glass rods are placed in numerical order in the front holes, and as they are used, they are replaced in the back row of holes. This system avoids confusion. The entire operation of adding the rings of glass takes only a few moments, once everything is prepared.

After the soft-glass tubing has been sealed onto mixture No. 8, the whole joint is reheated, shrunk, and reblown. This operation takes a great deal of care and patience, as the glass starting at the Pyrex-glass end has a high softening temperature, and this softening temperature gradually decreases as the soft-glass end is approached. So the joint, which

may be from $1/2$ to $3/4$ inch long, must be so rotated in the flame that each part acquires the proper temperature. Another difficulty is that the glass at the Pyrex-glass end sets much more quickly when removed from the flame. This point must be taken into consideration in the reblowing operation. With care and patience, a very neat joint can be obtained by this method.

A modification of the method of making the pyrex-to-soft-glass joint, which is somewhat easier in execution, is as follows: Make up the glass mixtures as before, but instead of using a Jena-*geräte* glass rod for No. 4, use a piece of Jena-*geräte* tubing 4 or 5 inches long which has the same diameter as the Pyrex tubing and the soft-glass tubing. Now proceed as before, starting with the Pyrex tubing. After glass mixture No. 3 has been applied, however, the Jena-*geräte* tubing is sealed on, and the whole joint of Pyrex tubing to Jena *geräte* is reheated and reworked in the flame until a smooth joint is obtained. Now, start with another piece of Jena-*geräte* tubing and add mixtures Nos. 5, 6, 7, and 8, finally sealing on the soft-glass tubing. Reheat this Jena-*geräte*-soft-glass joint and rework it until a smooth joint is obtained. Next, cut off the Jena-*geräte* tubing on each of the units about 1 inch away from the joint. Next, seal the two Jena-*geräte* ends of the units together. This completes the seal. The advantage of this method is that the joint is composed of two sections, each of which can be worked separately. After a little experience has been had, it will, generally, be found more convenient after sealing the Jena-*geräte* tube onto mixture No. 3 to cut the Jena-

geräte tube to a length of about 1 inch. Glasses 5, 6, 7, and 8 are then applied to its end, the soft-glass tube sealed on, and the second half of the joint finished by reheating and blowing. Figure 22 shows the arrangement of a Pyrex-to-soft-glass joint.

It is possible but *quite difficult* to make a series of mixtures of Pyrex glass and soft glass which can be sealed together by the method outlined. It is, however, *quite practical* to make such a seal by the use of Jena *geräte* as the intermediate glass. By the

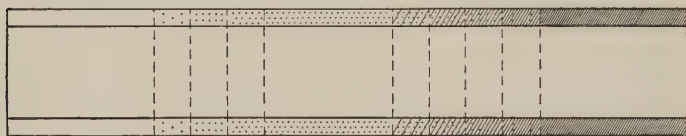


FIG. 22.—Diagram of Pyrex to soft glass joint. From left to right the sections are Pyrex glass; the 3 mixtures of Pyrex glass and Jena *geräte*; Jena *geräte*; the 4 mixtures of Jena *geräte* and soft glass; and at the right end, soft glass.

same system it is possible to seal Pyrex glass to quartz (silica) tubing.¹ Because of the very high temperature required to work quartz, however, this is a considerably more difficult operation.

Pyrex-to-soft-glass Joints with Commercial Glasses.

There is now available on the market² a series of five glasses, each differing successively by small increments in its coefficient of expansion and so chosen that it is possible to go from Pyrex to soft glass by using them as intermediate seals.³ These glasses are

¹ KEYES and KRAUS, U. S. Patent 1014757, describe a silica-to-glass joint by means of graded glasses.

² Corning Glass Works, Corning, N. Y.

³ TAYLOR, W. C. and AUSTIN BAILEY: *J. Ind. Eng. Chem.*, **13**, 1,158 (1921).

supplied in the form of tubing, and by their use an excellent graded Pyrex-to-soft-glass joint can readily be made without the inconvenience of preparing special glass mixtures.

To make the graded joint, first arrange the glasses in the following order:

Pyrex

G 750 AH

G 750 AI

G 750 AJ

G 750 AK

G 750 AL

Soft glass

The soft glass can be either the ordinary lime-soda glass or a lead glass. Next, place a cork stopper in one end of the Pyrex glass tube and then seal on the next glass in the series (G750AH). For a right-handed worker, the Pyrex glass tube should be held in the left hand. Now remove the cork stopper from the end of the Pyrex tube and draw off the G750AH glass tube, allowing about 1/4 inch to remain on the Pyrex tubing, by heating and drawing down and then finally drawing off the tail, as described on page 47. Finish up the 1/4 inch of G750AH glass by reheating in the flame and blowing gently to produce a rounded closed end of uniform thickness on the tube. Now reheat the extreme tip of the closed end strongly in a hot, pointed flame, so as to soften a circular region almost equal to the diameter of the tube. A strong, sudden puff blows this off into a paper-thin bulb, which can be scraped off easily with the file. Now

replace the cork stopper in the end of the Pyrex tube and repeat the same operation with the next intermediate glass, and so on. Finally, seal on the soft-glass tube, reheat the whole joint, anneal it carefully, and cool in a smoky flame.

Remarks.

It will be found that the various glasses will flow together freely and smoothly at all the joints except, perhaps, the one between Pyrex glass and G750AH. To insure perfect fusion and mixing of the glasses at this joint, a rather intense, hot flame should be used. It may be found helpful to heat the circumference, section by section, as described on page 36, so as to secure the necessary fluidity of the Pyrex glass without undue distortion of the joint. The joint can finally be completely heated up by rotating in the flame and blown in the usual manner.

Instead of sealing on short lengths of tubing, as just described, the joint may be made by first drawing the intermediate glasses out into the form of thin rods and then applying successive rings of glass, as described in the first method (p. 86).

SEALING GLASS TO PORCELAIN

Porcelain tubing is often used as the heat-resisting tube in combustion furnaces and in other pieces of apparatus in which the tubing must stand higher temperatures than about 500°C. It is frequently necessary, also, to have absolutely gas-tight joints between the porcelain tubing and glass tubing. A glass-to-porcelain seal can be made if the proper glass

is used. The glasses known as Pyrex and Nonex¹ have thermal expansivities sufficiently close to that of porcelain to be used for this purpose, although the Nonex glass is to be preferred, particularly if the porcelain tubing is more than 1/2 inch in diameter.

A glass connection to a porcelain tube, such as shown in Fig. 23, can be made in the following way: Nonex tubing is selected which will just fit over the end of the porcelain tube. If the tubing available is not large enough, it can be expanded slightly with the

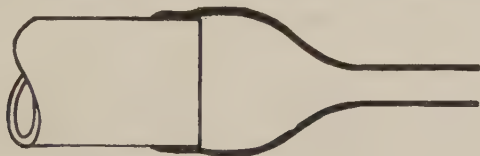


FIG. 23.—Glass to porcelain seal.

flanging tool. This tubing is then drawn down, and a smaller tube sealed to it, as shown in Fig. 12. The large tube is then cut off about 1 1/2 to 2 inches from the joint.

The porcelain and glass tubing are now rotated in the flame, and their ends heated slowly, to avoid cracking the glaze on the porcelain. When the glass begins to soften, it is slipped over the end of the porcelain tube so that it overlaps for a distance of about 1/4 inch. The heating and rotation are continued until the glass is in contact with the porcelain over the whole circumference. The joint is then heated quite hot, so that the glass "wets" the glaze and flows out freely to a smooth seal. The joint should be blown

¹ Nonex is a trade mark owned and used by Corning Glass Works, Corning, N. Y., and applied to a number of glasses. The glass herein referred to as Nonex has also been known as G702P.

as needed to prevent the glass from flowing over the end of the porcelain tube and is heated and worked until a symmetrical seal is obtained. It is then cooled slowly and carefully. The Nonex glass has a lower softening and setting point than Pyrex glass, and, by its use, the temperature range through which the rigid glass and porcelain must cool is decreased, and, hence, the possible strain decreased.

A Pyrex tube can be sealed to the Nonex tube, or a cone-and-socket joint (see Fig. 21) can be made and sealed with cement, since it will be some distance from the hot end of the furnace.

ETCHING OF GLASS

Glass is very readily etched by means of hydrofluoric acid. If lines, graduations, or figures are to be etched or engraved on glass, the procedure is, first, to coat the glass with a uniformly thin layer of some soft, acid-resistant substance. Wax or paraffin are commonly employed for this purpose. The glass can be dipped into the molten wax, or, if that is not convenient, the melted wax can be applied to the glass with a swab and melted down to a uniform coat by careful application of the flame of a Bunsen burner. When the coating is hard, the design is cut through the wax to the glass. A phonograph needle serves very nicely for "scratching" the wax. Some guide should be employed if straight lines are to be drawn. The scratches are then filled with hydrofluoric acid by means of a cotton swab on the end of a wooden stick, such as an applicator. After the line has been etched to sufficient depth, as determined by preliminary test,

the acid is washed off and the wax removed. To make the marks readily visible, they can be filled with red lead, white lead, printer's ink, or some similar substance. A *uniform* adherent coating of wax, not too thick or too thin, too hard or too soft, is a prerequisite for successful etching.

CHAPTER VI

GLASS-TO-METAL SEALS AND JOINTS

SEALING IN PLATINUM WIRE

Very often, it is necessary to seal platinum wire into the wall of a tube. Professional glass blowers usually use a special sort of glass (*Einschmelzglas*), which is usually a lead glass and is made of such composition that it has the same or practically the same coefficient of expansion as platinum. A little globule of this glass is sealed into the tube in such a way that it joins the platinum to the glass of the tube. To do this, the small globule of special glass is fused on the platinum wire at the proper point, and the tube into which the wire is to be sealed is heated and a small tail drawn out at the point where the wire is to be inserted. The lump of the special glass should be from $3/32$ to $1/8$ inch in diameter, and the tail drawn on the tube should have a slightly less diameter at the point (about $1/8$ inch or less from the tube) where it is cut off. There are now two ways of sealing in the wire. (1) The wire with the globule of glass is placed inside the tube, and the latter revolved until the end of the wire sticks out of the cut tail *a* (Fig. 24). The latter is now gently heated, and the two glass surfaces fused together, taking care to use only the end of the hissing flame, if the special glass contains lead (see Chap. I, p. 9). The whole circumference of the tube is then

heated and annealed carefully. (2) The end of the wire which is to be outside the tube is attached to the end of a thin scrap of glass, by heating the glass and thrusting the wire into it a very little way. Using this piece of glass as a handle, the wire is inserted in the cut tail *b* (Fig. 24), and the globule brought near to the end of the tail. (If the main tube is cold, it must, of course, first be warmed.) With the end of the "hissing" flame, as in the first method, the globule of glass is melted and the end of the tail softened.

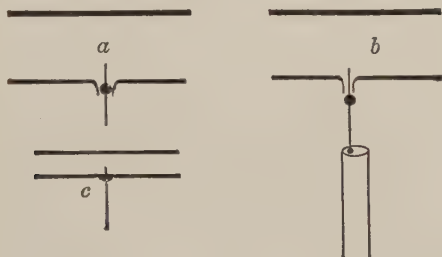


FIG. 24.—Sealing in platinum wire.

The wire is now pushed into place, the handle removed by heating the end and withdrawing it, and the tail reheated a little, if necessary, to make it shrink back into line with the walls of the tube. The whole circumference of the tube is heated at that point and annealed, as usual.

The use of this special glass is not absolutely necessary if the platinum wire is small ($1/4$ millimeter or less in diameter), and, in fact, it is often better, in such cases, not to use it, unless the apparatus is to be subjected to a very high vacuum. On small tubes, especially, it is undesirable to use the special glass, as a

lump of it will usually cause the tube to crack on cooling. When such glass is not at hand or is not to be used, the procedure is altered somewhat. The tail which is drawn out is very fine, having only a sufficient diameter so that, when it is cut off, the wire can be inserted in it. Such a fine tail is readily made by heating a small spot on the tube, touching it with a warm platinum wire, removing from the flame, and drawing out the tail with the wire. After cutting off the tail, the wire is inserted in it, being held on a scrap of glass, as in the previous case, and the wire and tail heated until the latter shrinks back into line with the walls of the tube. If too-great shrinkage occurs, the place may be blown out gently after reheating. Thus, the wire is sealed through the wall of the tube without changing the thickness of the latter and, consequently, without developing undue stresses at that point. Such a joint must, of course, be carefully reheated and annealed. With fine platinum wire, there is very little risk of the tubes cracking, if care is taken to avoid formation of any lump and to reheat the whole circumference of the tube at that point.

Any glass adhering to the end of the platinum wire, where the scrap of glass was sealed on for a handle, may be removed when the glass has cooled by crushing it carefully with a pair of pliers.

Platinum has commonly been used in making seals through soft glass, because it does not oxidize while glass is being applied, and, thus, glass and clean metal can come into contact, and, also, because soft and lead glass and platinum have almost the same coefficient of expansion.

GLASS-TO-METAL JOINTS WITH SOLDER

It is sometimes necessary in building apparatus to make pressure- and vacuum-tight joints between glass tubing and metal tubing. In recent years, many widely different methods have been developed for accomplishing this purpose.

A platinum wire sealed into a piece of glass is one of the most familiar of laboratory devices. Platinum does not oxidize while the glass is being applied, so that the glass, in melting down, comes in contact with a clean metal surface. Platinum and soft glass, also, have about the same coefficient of expansion, so that undue strains are not apt to be set up between the glass and the metal. It is but a step from sealing platinum wire into glass to sealing platinum tubing to glass tubing. The platinum tubing should, preferably, have a wall thickness of about 0.1 to 0.15 millimeters and should fit snugly into the glass tubing. Insert the platinum tubing into the glass tubing for a distance of about 1 centimeter. Now, apply a gentle flame to the end of the glass tubing, while rotating both pieces of tubing. Gradually increase the flame, and melt down onto the platinum tubing about 5 or 6 millimeters of glass tubing, commencing at the end of the glass tube. Heat hot enough so that the glass flows quite freely. If necessary, remove from the flame and blow gently, to keep the glass from lapping over the end of the platinum tubing. Finally, cool the joint slowly and anneal it carefully in a smoky flame. Any other metal tubing may now be soldered onto the platinum tubing. This type of joint is not very

commonly used, and, moreover, it is rather expensive, because of the use of platinum tubing.

A more common type of joint is the glass-to-metal soldered joint. The following procedure gives good results.¹ Choose glass tubing which will fit snugly into the metal tube for 15 or 20 millimeters of its length. It is convenient, but not absolutely essential, to have the glass tubing fit against a shoulder in the metal tubing. The inside of the metal tubing is tinned up to the shoulder with commercially pure tin. A slight excess of tin should be left on the surface, particularly if the tubes do not fit very closely. Allow the metal part to cool, and scrub the inside thoroughly with water, and dry. Clean the outside of the glass tubing near the end to be soldered, and platinize a length of about 20 millimeters by applying a colloidal solution of platinum.² One or two drops of this mixture are applied to the slightly warmed surface and flowed into a film. This is now gradually heated very slowly in a Bunsen flame to drive off the volatile material and, finally, heated to incipient red heat to burn off the carbonaceous residue and fuse the platinum into the glass. One application of platinum is generally sufficient. If the coating seems too thin, the operation may be repeated. Now, heat the glass tubing and metal socket gradually over a low Bunsen flame until the tin is well melted. The glass part is now inserted into the metal tube, and the whole is allowed to cool slowly and uniformly. The platinum surface should not be

¹ McKELVY and TAYLOR: *J. Am. Chem. Soc.*, **42**, 1,364 (1920).

² Directions for making this solution are given in the appendix.

tinned before making the joint, as the platinum is likely to be removed in this operation.

There are many variations to the above procedure. Lead, ordinary solders, and low-melting-point solders may be substituted for the tin. Also, excellent joints can be made without the step of platinizing the glass tubing. The following simplified procedure without platinum gives a very satisfactory joint: When joints are made without platinizing, both the glass and the metal must be very clean. Clean the glass with chromic acid, wash with distilled water, and dry. Next, coat the inside of the metal part with tin or solder, and clean the surface of the melted material with a zinc-chloride solution. Allow the metal part to cool, and then wash it thoroughly with distilled water. If necessary, scrub the inside with cotton or other material which is dirt and grease free. Finally, dry the metal part thoroughly. Now, hold the two parts above a fairly low Bunsen flame, and, as soon as the tin melts, insert the glass into the metal without the addition of flux. If one part is fixed on a piece of apparatus and it is inconvenient to use a torch, a soldering copper, just hot enough to melt the tin, may be held against the outside of the metal part, and the glass pushed in slowly as the tin melts.

SEALING IN BASE METALS

Platinum is so expensive that, in recent years, base-metal wires which have approximately the same coefficient of expansion as soft glass have been employed for sealing in glass. The alloys are chiefly of iron and nickel. One combination consists of a

nickel-iron alloy sheathed with platinum; another consists of a nickel-iron alloy sheathed with copper. This last-mentioned material is, also, usually coated with dehydrated borax. These alloy wires are sealed through glass in approximately the same manner as is platinum, except that it is not necessary to coat the alloy with special seal-in glass before making the seal.

As Pyrex glass has a much smaller coefficient of expansion than platinum, it is practically impossible to obtain a gas-tight seal between these two materials. Tungsten, on the other hand, has nearly the same coefficient of expansion as Pyrex glass and can usually be sealed through it. It is better, however, to use a seal-in glass having more nearly the same coefficient as tungsten in making the seals. A type of glass known as Nonex has this property. As tungsten oxidizes easily in the flame, special precautions must be taken to minimize oxidation. Tungsten wire may be successfully sealed through Pyrex glass by the following procedure: Draw down a piece of Nonex glass so that its internal diameter is just a trifle greater than the diameter of the tungsten wire. Slip a short piece of this glass tubing on the tungsten wire, and heat the glass in the flame so that it shrinks firmly onto the surface of the tungsten. Now seal this glass through the Pyrex tube in the usual manner.

A modification of the above method may also be employed, if trouble is encountered in keeping the tungsten wire bright and in making it adhere to the glass. This consists in putting a thin coating of fused potassium nitrite on the tungsten wire before introducing the wire into the small-diameter, Nonex-

glass tube. The remainder of the procedure is just the same as that described in the preceding paragraph.

The methods described above were all concerned with sealing a wire of circular cross-section through glass having approximately the same thermal expansivity as the wire. W. G. Houskeeper¹ has found that, if the cross-sectional shape of the material to be sealed through the glass is so altered that the stress between the metal and the glass is less than the shearing strength of the joint, almost any metal can be sealed through almost any glass, regardless of its coefficient of expansion. It is essential that the glass wet the metal when hot and, of course, necessary that the metal do not melt at the temperature used in making the seal.

Method 1.

To seal a fine (34-gage) copper wire through glass, first place the wire on an anvil and strike it with the sharp edge of a hammer in order to flatten it down to a thickness of approximately $1/1000$ inch and a width of about $3/100$ inch. Coat the flattened portion of the wire with dehydrated borax, and then insert the flattened and coated portion in the glass tube. Heat the glass to softening point and press it into firm contact with the flattened wire. Heat the joint to as high a temperature as the glass and metal will stand safely and, finally, anneal the joint and allow it to cool slowly. The borax next to the copper seems to provide a low melting point material, which decreases

¹ HOUSKEEPER, W. G.: "The Art of Sealing Base Metals through Glass," *J. Am. Inst. Elec. Eng.*, **42**, 954 (1923). The three methods of this section are those described by Houskeeper.

the temperature difference over which the copper is stretched upon cooling. This type of joint is successful because as the joint cools off the copper stretches, and the maximum stresses which this thickness of copper can exert in cooling is less than the shearing stress of the joint.

Method 2.

For a ribbon seal, procure a piece of copper sheet 15/1000 inch thick, and cut a piece of ribbon from it about 1 inch wide and approximately 4 inches long. File away the edges for about 1 inch at the center so that the edges are sharp like a knife blade with angles of about 8 or 10 degrees. Flatten the glass tubing, into the end of which the copper ribbon is to be sealed, so that the opening is approximately $1 \frac{1}{8}$ inches by $\frac{1}{8}$ inch. The copper ribbon is now heated to a red heat. At the same time, the end of the glass tube is heated almost to its softening point. Now introduce the copper ribbon into the end of the glass tubing so that the sharpened knife edge part is in the flattened section of the tubing. The whole is now heated and the glass pressed into contact with the ribbon and heated to as high a temperature as the glass and copper can stand without injury. Now anneal the seal and allow it to cool off slowly.

A definite size of copper ribbon has been specified above only in order to illustrate the principles of the operation. When the glass is heated to the temperature at which it is applied to the copper, it has the consistency of rather thin molasses and wets copper very readily. As the glass and copper cool off, the adhesion of the glass to the copper is stronger than the

cohesion of the glass itself. The adhesion of the glass to the copper is entirely independent of the thickness of the copper or the thickness of the glass but the stresses which the joint may be called upon to resist are directly dependent upon the thickness of the glass or the copper or both. By the employment of a ribbon, the perimeter of the cross-section becomes very great as compared with its area, and by tapering off the two edges to very sharp angles, the whole section is so proportioned that the stress between the metal and glass is always less than the shearing strength of the joint. The sharpened, knifelike edges on the metal are very essential. Naturally, other sizes of metal and other metals may be used in making this type of seal, as long as the above principles are adhered to. Copper is peculiarly satisfactory in making such a seal, because copper passes its elastic limit at a comparatively low unit stress.

Method 3.

For a disk seal, a copper disk and two pieces of glass tubing are necessary. Flare one end of each of the pieces of glass tubing. The disk should be a little larger in diameter than the flared ends of the tubing. Support one of the glass tubes vertically with the flared end uppermost and place the disk on top of the flare, properly centered. Now, heat the flared end with the portable hand-blast flame, until the glass softens slightly and the copper disk adheres to the glass. Using the glass tube as a handle, heat the joint in the flame of the blast lamp and seal the second piece of tubing onto the other face of the disk by pushing the softened, flared end, properly centered,

against the disk. Finally, heat the joint to a temperature as high as the glass and metal will stand, and then cool the joint carefully.

Particular pains should be taken to prevent the glass on one side of the disk from running over the



FIG. 25.—Copper disk seal.

edge and fusing with the glass on the other side of the disk, as this would cause the seal to break. If the joint is going to be put to some use in which it will be alternately heated and cooled through a rather large range of temperature, a thin disk of



FIG. 26.—Copper disk seal with lead-in wire.

copper should be used; but if the joint is going to remain at room temperature, no great care in choosing the disk is necessary. The glass tubing on one side may be cut off close to the face of the disk, and a round wire passed through a hole in and soldered to the disk. In the disk type of seal, the copper disk is stretched radially in all directions upon cooling. Figures 25 and 26 illustrate this type of seal.

Sealing Copper Tubing to Glass Tubing.

Houskeeper has also described some very ingenious methods for sealing glass tubing to copper tubing.

It was found that if the size and shape of the materials were proportioned properly so that the stress between the metal and the glass was always less than the shearing strength, it was entirely possible to seal practically any metal to glass, provided that the glass wets the metal when hot, and, further, provided that the metal does not melt at the temperature necessary for it to be wetted by the glass.

Method 1.—In this method, the end of the copper tube is spun outwardly, so that a cone-shaped flange results. The copper flange and glass tubing are heated up to the softening point of the glass, and the end of the glass tube pressed against the flange.



FIG. 27.—Glass sealed to flanged copper tube.

Reheat, and blow the glass gently, if necessary, to keep it in shape, and cool the joint gradually and carefully in the flame. Figure 27 shows, in diagram, the appearance of such a joint. The disadvantage of this type of seal is that the joint itself is of much greater diameter than the tubes from which it is made.

Method 2.—In this method of sealing copper tubing to glass, the end of the copper tubing is turned down on a lathe, until a thin wall of copper remains. The next step is to melt a ring of glass onto the outside of this thin wall and then seal this glass to a glass tube which just slips over the outside of the copper tubing; cool gradually. The success of this joint depends

upon the fact that, although the copper is under tension as the joint cools, yet the adhesion of the glass to the copper is sufficient to stretch the copper as it cools. Do not allow any glass to run across the end of the copper tubing, as any glass which runs over the end of the tube impedes the reduction in thickness of the copper tubing and causes the seal to



FIG. 28.—Glass sealed to copper tube (Method 2).

crack. Figure 28 shows, in diagram, the appearance of a seal constructed according to this method.

Method 3.—For this procedure, machine the copper tubing at one end so as to provide a thin wall of copper, and turn the edge of this thin copper tube down to a knife edge. A ring of glass is then melted onto the outside of the thin tube, and the glass tubing



FIG. 29.—Glass sealed to copper tube (external seal).

sealed to this layer of glass. Cool the seal carefully. This is a safer type of seal to make than the one described in Method 2, as the introduction of the knife edge on the copper tube changes the possible stress between the glass and the copper, if glass should happen to flow over the end. With this knife edge present, should any glass pass over the edge, failure of the seal is not likely to occur, as the size and shape of the articles are here such that the stress between the metal and the glass is less than the

shearing strength. As the glass is applied outside the copper, this type of seal is known as an *external seal*. Figure 29 shows a seal of this type.

Method 4.—For this procedure, the copper tubing is machined down just as described in Method 3. The next operation is to apply a ring of glass to the inside of the copper tubing with a piece of glass rod of small diameter. The glass tubing is now sealed to this glass. As the glass is applied and sealed on the inner side of the copper tubing, this type of seal is known as an *internal seal*. Figure 30 shows a seal of this type.



FIG. 30.—Glass sealed to copper tube (internal seal).

There is a distinct difference in the behavior of the internal and the external seals, even when the seals are made with the same dimensions of copper tubing. An internal seal will resist sudden heating much better than an external seal, while an external seal will resist sudden cooling much better than an internal seal. There seems to be practically no limit to the size of copper tubing which can be joined to glass tubing. The important thing is to reduce the thickness of the copper tubing over that portion which comes in contact with the glass.

Although there is considerable latitude in the range of metals and glass which can be sealed together by the Houskeeper methods, nevertheless, for the beginner, certain combinations will prove the easiest to handle. Soft glass seals readily to copper, but Pyrex glass, because of its higher softening point, requires greater attention to the proportioning of the

parts. Nonex glass has a lower softening point than Pyrex glass but has very nearly the same thermal expansivity, so that it can readily be sealed to it. This offers a simple way of sealing soft glass to Pyrex glass. The soft glass is sealed to one end of a short length of copper tubing by one of the methods described. A piece of Nonex glass is then sealed to the other end of the copper tube, and the Pyrex tube sealed to the Nonex glass.

APPENDIX

PLATINIZING SOLUTIONS

There are a number of formulas for the preparation of solutions for platinizing glass. The solutions prepared by the following methods have proved equally satisfactory:

Method 1.

Ten per cent platinic chloride solution, equivalent to 1 gram of platinic chloride, is evaporated to dryness in a porcelain evaporating dish and dissolved in a minimum quantity of absolute alcohol. This solution is added very slowly, with stirring, to 6 cubic centimeters of lavender oil cooled in ice. Burgundy pitch is then added to the solution, until the latter has the desired consistency.

Method 2.

One part of pure neutral platinic chloride, prepared by evaporating a 10 per cent solution to dryness, is moistened with a few drops of absolute alcohol and ground in an iced mortar with 10 parts of lavender oil. The lavender oil is added gradually in small quantities.

For coating glass, as a preliminary step in soldering it to metal, as described in this book, the consistency of the platinizing solution is of little importance. Platinizing solutions which have been kept for several years gradually thicken when exposed to the air, but no platinum has been deposited, and the solutions can still be used with satisfactory results. Ordinary rosin can be substituted for the Burgundy pitch with very satisfactory results.

In using the solution, a thin film is flowed onto the previously warmed glass which it is desired to coat. The glass is then carefully heated over a Bunsen flame to drive off the volatile material and, finally, to incipient redness to fuse the reduced metallic platinum into the glass.

STOP-COCK LUBRICANTS

A good stop cock needs the proper lubricant in order to function satisfactorily, particularly where it is to be used in handling gases or in high-vacuum work. The lubricant should permit the plug to turn

smoothly and should have sufficient body to keep it in place on the surface it is lubricating. For high-vacuum work, it should also have a very low vapor pressure. These requirements are not readily met, as has been shown by Shepherd and Ledig, as well as others who have investigated the subject.

Shepherd and Ledig¹ recommend three mixtures of the rubber-vaseline type. The high-vacuum lubricant contains the highest percentage of rubber and is quite viscous. The mixture for general use is suitable for most laboratory work, including the manipulation of gases, while the light mixture can be employed for lubricating buret cocks and the like, which must turn very easily.

HIGH VACUUM

	Parts
Pale crepe rubber.....	31
Vaseline (white).....	24
Paraffin, melting point 36°C.....	5

GENERAL

Pale crepe rubber.....	6
Vaseline.....	7
Paraffin.....	1

LIGHT

Smoked sheet or pale crepe rubber.....	10
Vaseline (white or yellow).....	18
Paraffin, melting point 36°C.....	1

The mixture should be heated in an oven to 155°C. and stirred continuously for 190 hours. It is then poured in small portions (1/4-inch layers) into 2-ounce ointment cans and immediately chilled by placing on ice, in order to produce a fine-grained product. After aging for about 10 days, it should be suitable for use. The reader is referred to the article by Shepherd and Ledig for further information on the subject.

VACUUM WAX

FORMULA No. 1

Melt up equal parts of beeswax and rosin. Stir thoroughly until they are completely mixed. Cast the material into sticks 3/16 to 1/4

¹ SHEPHERD, and LEDIG: "Rubber Stopcock Lubricants for High-vacuum and Other Uses," *J. Ind. Eng. Chem.*, **19**, 1,059 (1927).

inch in diameter. This wax can be made a little harder or softer by varying somewhat the proportions of the ingredients. It is useful in sealing cone-and-socket joints and the like.

FORMULA No. 2¹

Dissolve 10 to 20 per cent of pure gutta-percha in molten beeswax. Cast the resulting product into sticks.

DE KHOTINSKY CEMENT

De Khotinsky cement is essentially a pine-tar-shellac mixture. It is frequently mentioned in the literature and has come to be generally used throughout the laboratories of the country. The manufactured article is much better than the usual home-made variety. The cement comes in three grades, hard, medium, and soft; the hard variety is best for most laboratory work.

To apply the cement to glass, first clean the glass. Then slowly heat the glass up to about 120 to 140°C., and, at the same time, warm the cement over a small flame until it is quite soft but not flowing. Now, touch the stick of cement to the tube, and allow sufficient cement to flow onto the glass to make a thin layer. Next, press the other part, previously warmed to 120°C. or so, onto the cement. The excess of cement will flow out from between the parts, and a gas-tight joint will result. Allow the joint to cool completely without moving any of the parts. To break the joint, heat it gently up to the temperature at which the cement softens, and pull the parts apart. The surplus cement can be removed from the glass by keeping the latter hot and wiping the former off with a piece of cloth. The remaining cement can be washed off with alcohol. The cement can be successfully applied to glass, metal, porcelain, wood, etc.

CEMENT

A material similar to De Khotinsky cement, and a possible substitute for it on cone-and-socket joints, is a shellac and wood-tar composition. This cement is made by melting together intimately from 60 to 80 per cent by weight of shellac and from 40 to 20 per cent by weight of wood tar. It is impossible to give very definite directions as to the exact materials and amounts to use, as tars vary very widely in their physical properties, and not all tars are suitable. Keyes² mentions the use of a somewhat similar mixture in cementing a ground joint of glass to steel.

¹ COTTRELL, F. G.: *J. Am. Chem. Soc.*, **34**, 1,330 (1912).

² KEYES: *J. Am. Chem. Soc.*, **40**, 28 (1918).

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